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THE TOLERANCE OF VARIOUS FORAGE CROPS TO
SALINITY, WITH SPECIAL REFERENCE
TO SEED GERMINATION.

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UNIVERSITY OF ALBERTA.

APRIL, 1956.

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ABSTRACT

Using uncovered, sub-irrigated sand cultures, the addition of calcium was found to ameliorate the toxic effects of pure solutions of sodium chloride on the germination percentage and leaf growth of Ladak alfalfa (Medicago media), reed canarygrass (Phalaris arundinacea), Alta fescue (Festuca arundinacea) and tall wheatgrass (Agropyron elongatum). Another comparison was made of the effects of sodium sulphate and sodium chloride, each alone and in combination with calcium, on the germination and seedling growth of Alta fescue. The sulphate was more toxic than the chloride, and calcium ameliorated the effects of both salts, but did not alter the effect of one relative to the other.

Using covered, sub-irrigated sand cultures, the effects of different salts in combination with base nutrient solution, on the germination and seedling growth of Alta fescue were determined. The osmotic pressures in atmospheres of the different salts found to reduce germination percentage to 50 percent of the check are summarized as follows: NaCl - 16.3, MgCl₂ - 15.2, MgSO₄ - 13.3, Na₂SO₄ - 12.4, and CaCl₂ - 12.4. Using a mixture of sodium sulphate and magnesium sulphate, the reduction of germination to 50 percent of check for three species was as follows: Ladak alfalfa - 9.8, Alta fescue - 14.3 and tall wheatgrass - 16.7.

An attempt was made to relate results from artificial germination studies to results from field studies, where the total soil moisture stress (atmospheres) was estimated by determination of the osmotic pressure of the saturation extract, and the capillary potential at the appropriate moisture content. Fair agreement was obtained in most instances, but some other factors involved were brought out in the discussion.

315
56
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THE UNIVERSITY OF ALBERTA

THE TOLERANCE OF VARIOUS FORAGE CROPS
TO SALINITY, WITH SPECIAL REFERENCE TO SEED GERMINATION

A DISSERTATION
SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
OF MASTER OF SCIENCE

FACULTY OF AGRICULTURE
DEPARTMENT OF SOILS

by
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EDMONTON, ALBERTA.

APRIL, 1956.

ACKNOWLEDGEMENTS

The writer wishes to express his appreciation to Mr. R.W. Peake, of the Experimental Farm, Lethbridge, under whom this work was initiated.

Many thanks are also due to Dr. J.D. Newton, Professor of Soils at the University of Alberta, under whose guidance this thesis was written.

Acknowledgement is made to Mr. R. Milne of Prairie Farm Rehabilitation Administration, Vauxhall, for analysis of samples appearing in Table XI.

To all members of the staffs of the Dominion Experimental Farm Service, Science Service, Prairie Farm Rehabilitation Administration and the University of Alberta, who have helped in many different ways, I wish to extend my thanks.

TABLE OF CONTENTS

<u>SUBJECT</u>	<u>PAGE</u>
Introduction	1
Literature Review:	
Classification of Saline and Alkaline Soils	4
The Osmotic Pressure of Solution	5
Total Soil Moisture Stress	7
Calcium and Ion Antagonisms	9
The Comparison of Different Salts	13
The Influence of pH on Plant Growth	14
The Effect of Climate on Salt Tolerance	16
The Effect of Salinity on Seed Germination	16
Field Trials	18
Germination Experiments:	
Methods	19
Statistical Treatment	22
Plant Material	23
Preliminary Experiments	24
The Relative Tolerances of Chloride and Sulphate	25
Calcium Amelioration of Toxicity of Other Salts	28
The Effect of Temperatures on Germination in Saline Cultures	34
The Comparison of Different Salts Using Covered Dishes	36
Comparison of Species on a Mixture of Salts	46
Introduction Nurseries:	
Methods	49
Stand Establishment Data	49
Yield Data	57

TABLE OF CONTENTS (Cont'd)

<u>SUBJECT</u>	<u>PAGE</u>
General Discussion of Results	59
Bibliography	60
Appendix:	63
Procedure for Making up Salt Solutions	70
Procedure for Freezing Point Determinations	71

LIST OF PLATES

Plate I	30
(a) The effect of calcium deficient distilled water compared to calcium deficient base nutrient solution on split barley roots being supplied calcium through another root in calcium carrying nutrient solution.	
(b) The ameliorating effect of calcium on the toxicity of NaCl to germinating seeds of Alta fescue.	
(c) The effect of different salts at 16 atmospheres osmotic pressure on the germination of Alta fescue.	
Plate II	53
(a) Introduction nursery on a saline seepage area at Lethbridge, 1955.	
(b) Same nursery as above, after cutting and recovery from cut.	

LIST OF TABLES

	<u>PAGE</u>
Table I. Salt Concentrations of Typical Alberta Saline Soils, Obtained from Alberta Soil Survey Bulletins and Converted to Millimoles per 100 Grams of Soil.	6
Table II. The Effect of Increasing Osmotic Pressures of Sodium Chloride on the Germination Percentage of Four Forage Species, as Determined in Uncovered Dishes, Sub-irrigated from Small Reservoirs.	26
Table III. The Effect of Increasing Osmotic Pressures of Sodium Chloride and Sodium Sulphate in Uncovered, Sub-irrigated Sand Cultures, on the Germination and Leaf Growth of Three Forage Species.	27
Table IV. The Effect of Addition of Calcium Chloride on the Toxicity of Sodium Chloride to the Germination and Seedling Growth of Various Forage Species, Determined in Uncovered, Sub-irrigated Sand Cultures at 21°C.	29
Table V. The Effect of Addition of Calcium on the Toxicities of Sodium Sulphate and Sodium Chloride, to the Germination, Leaf Growth and Root Growth of Alta fescue (<u>Festuca arundinacea</u>), Determined in Uncovered, Sub-irrigated Sand Cultures at 21°C.	32
Table VI. The Effect of Temperature and Salt Concentration on the Germination of Alta fescue (<u>Festuca arundinacea</u>) and Reed canarygrass (<u>Phalaris arundinacea</u>).	35
Table VII. Composition of Base Nutrient Solutions Used in the Three Experiments Recorded in Tables VIII, IX and X, Concentrations Being Those of the Final Solution.	37
Table VIII. The Osmotic Pressures of Salt Solutions as Calculated and Determined by the Freezing Point, and their Effects on the Germination and Seedling Growth of Alta Fescue (<u>Festuca arundinacea</u>).	39
Table IX. The Effects of the Sulphates and Chlorides of Magnesium and Sodium, of Calcium Chloride and of a Mixture of Sodium and Magnesium Sulphates, with Base Nutrient Solution, all at an Accurately Adjusted Osmotic Pressure of 16 Atmospheres, and pH of 6.0, on the Germination of Alta Fescue (<u>Festuca arundinacea</u>).	44
Table X. The Germination Percentage and Seedling Weight of Three Forage Species as Affected by Increasing Concentrations of a Mixture of Sulphates of Magnesium and Sodium with Base Nutrient Solution, in Covered, Sub-irrigated Sand Cultures.	47

LIST OF TABLES (Cont'd)

	<u>PAGE</u>
Table XI. The Chemical Analyses and Conductivities of Saturation Extracts, the Conductivities of Soil Pastes, and the pH Determinations of Surface Soil Samples Taken from Three Different Locations in a Plant Introduction Nursery at Lethbridge, Alberta, 1954.	51
Table XII. The Conductivity of the Saturation Extract and the Determination of Total Soil Moisture Stress in Atmospheres by Summation of Osmotic Pressure of Soil Solution as Determined by Freezing Point Depression and an Estimated 0.17 Atmospheres Soil Moisture Tension, Determined on Surface Samples from an Introduction Nursery at Vauxhall, Alberta, 1955.	55
Table XIII. The Effect of Soil Salinity, Previously Shown in Table XII, on the Percentage Stand Establishment of Various Forage Crops in an Introduction Nursery at Vauxhall, Alberta, 1955.	56
Table XIV. Tons of Forage, Dry Matter per Acre, Harvested from Plots Replicated Four Times on a Saline Seepage Area at the Canada Experimental Farm at Lethbridge, Alberta.	58
Table IA. The Calculation of Osmotic Pressures from Freezing Point Data from International Critical Tables.	65
Table IIA. Conversion of Molal Concentrations to Molar Using Density Data from International Critical Tables.	67
Table IIIA. In Vacuo Weighings of Molecular Weights of Various Salts and of 1,000 Grams of Water.	68

LIST OF FIGURES

Figure I. The Effect of Increasing Osmotic Pressures of the Chlorides of Sodium, Calcium and Magnesium, and of the Sulphates of Sodium and Magnesium on the Germination Percentage of Alta Fescue (<u>Festuca arundinacea</u>).	40
Figure II. The Effect of Increasing Osmotic Pressures on Germination Percentage, Dry Matter per Seedling and Length of Leaf per Seedling of Alta Fescue (<u>Festuca arundinacea</u>), all expressed as a Percentage of Check.	41
Figure III. The Germination Percentage of Ladak Alfalfa (<u>Medicago media</u>), Alta Fescue (<u>Festuca arundinacea</u>) and Tall Wheatgrass (<u>Agropyron elongatum</u>) as Affected by Increasing Osmotic Pressures of a Mixture of the Sulphates of Magnesium and Sodium Plus Base Nutrient Solution.	48

THE TOLERANCE OF VARIOUS FORAGE CROPS
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INTRODUCTION

When the concentration of soluble salts is excessive in agricultural soils, crop production is adversely affected. Such soils are commonly called "alkali" or "saline" soils. Technically speaking, these terms are specific for somewhat different conditions, elaboration of which will follow in the literature review. It is sufficient to say here that the term saline refers to soluble salts while the term alkali refers to a dispersed condition of the soil colloids.

Salinity and alkalinity are typical of soils of arid and semi-arid climates, where evaporation is high and rainfall is low. Under such circumstances ground waters tend to flow to low, poorly drained locations. Evaporation, being the predominant process, causes a movement of water toward the surface, where dissolved salts are deposited. Under dry land farming or ranching, operations are generally extensive rather than intensive, and the value of the land rendered unproductive is not a very important factor.

However, with the advent of irrigation, the importance of soil salinity is magnified by the following factors: (1) the condition is aggravated and extended by irrigation; (2) the high capitalization of the land demands more effective use of marginal areas; (3) when these areas are left uncultivated, they become harboring places for weeds, which are undesirable because of their unsightly appearance and for the fact that they are a source of contamination.

Unpublished data obtained by the Alberta Soil Survey, with co-operation of Prairie Farm Rehabilitation Administration, covering the irrigable areas of the Magrath - Raymond, Monarch, Tilley and Patricia - Millicent districts, indicate that of 145,047 acres surveyed, 18,452 (13.1%) were rated as moderately to strongly saline, and another 12,697 (8.8%) were rated as slightly saline. The irrigated acreage of southern Alberta is 595,000 acres by the latest estimate, and there is an estimated 1,720,000 acres potential by extension of present projects and development of the Red Deer Project. It is to be hoped that newer irrigation systems will benefit from the experience of the past, and be so constructed to minimize the salinity hazard. However, taking a modest estimate of even 10% on land now irrigated, a figure of practically 60,000 acres is obtained, and projecting into the future a potential of 170,000 acres of saline soil under irrigation might be anticipated.

The most satisfactory solution to the problem would be the lining of irrigation canals to prevent seepage; the drainage of waterlogged areas, followed by leaching; the use of gypsum or other soil conditioners if they are required in the latter process. However such projects are expensive, and indeed may not completely remedy the problem. Also many areas are too small to warrant extensive reclamation programs. If for one of the above reasons the land is not reclaimed, then the only alternative is to try to grow on the land crops which are tolerant.

Forage crops are a natural choice for such areas. There is an almost unlimited variety of species and strains from which to choose, and many are known to have a high tolerance to soil salinity and the

high water tables accompanying it. Again forage crops are generally perennial in nature, and so eliminate yearly spring work on these lands which are so often flooded or water-logged at that period of the year. Some of the specialty crops such as sugar beets are quite tolerant to soil salinity, but their position as a contract crop will prevent their use on poor lands. It then becomes the duty of forage workers to learn the relative tolerance of various forage species and strains to soil salinity and related conditions, and to search for new species and strains which are tolerant of extreme conditions, but still are of good agronomic value. Also, with the growing interest in irrigated pastures, a search must be made for suitable pasture mixtures possessing a fair amount of ecological stability for these areas.

The work herein reported has been directed to the following ends:

(1) to determine the reaction of various forage species to salinity under natural conditions, with respect to establishment, yield, and desirability from other points of view,

(2) to determine the maximum of a representative mixture of salts tolerated by germinating seeds and growing seedlings of a number of important forage species,

(3) to determine the effects of the different salts when used alone,

(4) to study means of interpreting data obtained from culture experiments with plants, so that it may be applied to soil conditions in the field as determined by chemical analysis of soil samples and general observations.

LITERATURE REVIEW

CLASSIFICATION OF SALINE AND ALKALI SOILS

Before entering into a discussion of plant relations to saline soils, the definition of the conditions themselves is necessary. Magistad (1945) in his review of the literature indicated the following processes as being involved in the formation of saline and alkali soils:

- (1) Salinization - salts usually accumulate in soils because of lack of sub-surface drainage. With evaporation and transpiration the salt concentration increases. Sodium salts may or may not predominate, but calcium salts precipitate out leaving a more concentrated sodium solution.
- (2) Alkalization - an equilibrium exists between the distribution of bases in the soil solution and on soil colloids. With high concentration of sodium in solution, it replaces other cations in the colloids.
- (3) Desalinization - if the soils are drained and leaching occurs, the other salts are removed, leaving a sodium soil which becomes deflocculated.
- (4) Degradation or Solodization - with desalinization a new equilibrium is set up between sodium colloids and the solution. If the soil is not calcareous, the sodium soil is hydrolysed giving a hydrogen soil and sodium hydroxide, which reacts with carbonic acid of the soil solution, giving sodium carbonate.
- (5) Regrading - if a supply of calcium is present it will replace the hydrogen of a degraded soil or the sodium in the case of a desalinized soil, the result being a normal soil.

Based on the assumption of such a genesis of these soil conditions, de Sigmond, as reviewed by Magistad (1945) suggested the following classification of saline and alkali soils:

- (1) Saline Soils - contain over 0.1% salt and less than 12% of the exchangeable cations Na and K, with pH usually less than 8.5.
- (2) Saline Alkali Soils - contain over 0.1% salt and over 12% of the exchangeable cations Na and K, with pH greater than 8.5.
- (3) Slightly Saline Alkali Soils - contain over 12% replaceable Na and K, with slightly over 0.1% salt and with a pH range 8.5 to 10.0.

- (4) Degraded Alkali Soils - contain less than 0.1% salt and appreciable quantities of replaceable hydrogen with pH usually 6.5 to 8.0 but may be as low as 6.0.
- (5) Regraded Alkali Soils - Ca and Mg have been added giving a normal soil.

An idea of the salts occurring in typical Alberta saline areas can be derived from Table I which has been summarized from a number of Alberta Soil Survey Bulletins. These data have been transformed from percentage values to millimoles per 100 grams soil to give a comparative value of the numbers of ions present. The data indicate that of the anions present, sulphate is by far the most abundant, being in the neighborhood of ten times the concentration of chloride, though in two instances they are about equal, where overall concentration was low. The carbonates and bicarbonates are again considerably less than the chlorides. Of the cations, sodium is generally the most abundant being generally about four times as concentrated as the magnesium, though in some instances they are equal, and in two instances magnesium is somewhat more concentrated than sodium. As these were determinations of soluble salts, and sulphates predominate, calcium salts are low because of the low solubility of calcium sulphate.

THE OSMOTIC PRESSURE OF SOLUTION

Eaton (1941) showed by a very interesting experiment that the toxicity of a concentrated salt solution may be largely due to a lack of water availability. The roots of individual corn plants were divided equally between two nutrient solutions of different concentration, one six times the osmotic pressure of the other. Seventy-six percent of the total water transpired came from the weak solution, and twenty-four percent from the strong solution. However there was greater root growth in the weak solution, which might have accounted for the difference, so another experiment was designed in which the roots were alternated between the two solutions each day. The growth of each set of roots was about the

TABLE I. Salt Concentrations of Typical Alberta Saline Soils, Obtained from Alberta Soil Survey Bulletins and Converted to Millimoles Per 100 Grams of Soil.

Location and Description	Horizon or Depth	MILLIMOLES PER 100 GRAMS SOIL					
		HCO ₃ or HCO ₃ & CO ₃	Cl	SO ₄	Ca	Mg	Na
Lethbridge - Pincher Creek 21-6-19							
No crop growth	Surface	0.34	2.39	21.85	3.97	6.85	24.78
	Sub-surface	0.18	0.70	12.36	2.32	3.17	14.00
	Sub-soil	0.36	0.40	12.45	3.20	2.92	13.50
Crop growth reduced	Surface	0.33	2.34	3.13	1.12	0.91	2.78
	Sub-surface	0.29	1.89	13.60	2.90	4.40	19.95
	Sub-soil	0.41	1.69	16.83	3.20	4.85	25.4
Rainy Hills Crust caused by irrigation							
	Surface	0.80	1.83	157.4	5.12	14.47	275.0
	Surface	1.51	2.55	157.8	26.9	28.3	175.7
Wainwright East of town							
	8" to 10"	0.46	6.05	9.05	2.14	5.35	9.65
	18" to 28"	0.39	0.59	11.80	5.30	5.18	3.65
	at 36"	0.54	0.14	1.63	0.37	0.78	1.61
Milk River 19-3-4							
	0" to 4"	0.49	0.31	1.39	0.92	0.54	0.04
	4" to 10"	0.44	0.20	7.00	3.70	2.06	2.52
	10" to 18"	0.48	0.42	9.34	5.12	2.26	2.87
Calgary 19-17-25							
	0" to 6"	0.59	0.25	4.56	0.76	0.12	13.83
	6" to 12"	0.39	0.28	18.86	3.25	0.12	30.4
	12" to 26"	0.33	0.35	14.00	0.75	0.08	27.6

same in this instance, sixty-five percent of the water uptake being from the weak solution, and thirty-five percent from the strong solution. The effect of high osmotic pressures of solutions in reducing water entry was also shown by Hayward and Spurr (1944) by using a potometric device attached to corn roots, and again Hayward and Spurr (1943) compared isosmotic solutions of salt and sugar and showed growth depression to be similar whether caused by salt or sugar.

Following the conclusion that the osmotic pressures of solutions were fundamental, a number of papers appeared in which different salts were compared on the basis of osmotic pressures, among them Gauch and Wadleigh (1942, 1944, 1951), Hayward and Long (1943), Magistad, et al (1943). These papers show that whereas the differences between salts are minimized on this basis, some differences still exist.

TOTAL SOIL MOISTURE STRESS

Not only is soil moisture withheld from the plant by the osmotic pressure of the soil solution, but by the adherence of the moisture to the soil particles. Wadleigh and Ayers (1945) showed that both these factors were additive in their effects on growing plants. The concept of the capillary potential as a measure of the attraction between soil and moisture was proposed by Buckingham (1907). Gardner (1937) states the idea in very understandable terms.

"If a water table stands below the soil surface, the tension at any point within the liquid, per unit cross sectional area at equilibrium is equal to the weight of a column of water of unit cross sectional area as high as the distance from the water table to the point. Since the weight of 1 cubic centimeter of water is 1 gram, the capillary tension in grams at any point above the water table at equilibrium is numerically equal to the height in centimeters from the water table to the point in question."

At low moisture contents, the capillary potential is very great, and may be more conveniently expressed as a log, in which case it is known as the pF. The pF curve varies with the individual soil, variations being largely a function of texture. Knowing the pF curve of a soil, it is possible to calculate the tension in atmospheres or any other unit desired, at the various moisture levels. Again, knowing the salt content of a soil, it is possible to calculate the osmotic pressure at any moisture percentage desired. Wadleigh (1946) showed how curves could be developed to aid in the calculation of soil moisture stresses. The curves are hyperbolic in nature and have the general formula.

$$t = \frac{k}{P_w^n} \quad \begin{array}{l} \text{where } P_w \text{ is percent water} \\ t \text{ is soil moisture tension} \\ k \text{ and } n \text{ are constants for the soil} \end{array}$$

Similarly the curve for osmotic pressure of the solution was derived, having the form $\Pi = \frac{k_\pi}{P_w^{n_\pi}}$, where Π is the osmotic pressure of the solution. Having derived the constants k and n for any soil, using pressure membrane data, and k_π and n_π depending on the salt used, it is possible to calculate the total stress P at any moisture percentage used by adding the two. Thus $P = t + \Pi$.

Ayers and Campbell (1951) used this method of calculating the moisture stress over a range of moisture values, using different amounts of added sodium chloride. When they compared the curves obtained to the total stress as obtained by the freezing point depression, there was good agreement between the curves over most of the range. Henderson (1951), was using the upper portions of these very same curves when he took the percent moisture and freezing point depressions of a series of soils in which plants wilted at different salt concentrations.

It may be mentioned here, that the freezing point method is often used to determine the pF curve of a soil. However it must be

remembered that in freezing point depression measurements moisture is removed from both salt and soil, so that the data are applicable to pF values only in soils of low salt content, or non-saline soils. Similarly vapor pressure measurements measure total stress. However in data obtained by centrifuge, tension plates, tensiometers and pressure membrane, the true capillary potential is being measured.

It is interesting to note here that in some respects tolerance to salinity is analogous to tolerance to drought. Such factors as high concentration of cell sap and mechanisms of reducing transpiration might be expected to affect both. The data of Harris et al (1924) indicates that in general, plants growing on saline soils have a higher osmotic pressure of the cell sap than those on non-saline soils, though at the same time woody plants analysed had a higher concentration than herbaceous plants. Iljin (1927) has shown that plant cells die by drying, not necessarily because of the dehydration of the protoplasm, but because the protoplasm is torn by dehydration.

CALCIUM AND ION ANTAGONISMS

The calcium nutrition of plants has an effect on their response to salinity, and is especially important to this work in two respects: (1) it has been found that in certain alkaline soils, if the base exchange portion of calcium is below a certain level, that calcium deficiency is apt to occur, as reviewed by Stout and Overstreet (1950). (2) in doing research on the toxicities of other salts, it is important to assure that optimum amounts of calcium are present, or, if so desired, that it be deficient to a known degree. Palmer (1935) recognized and investigated the practical importance of calcium in ameliorating the effects of soil salinity on crop growth. The importance of other ions is definitely not as great as that of calcium in respect to this so-called antagonism, but in any case the

possibility of similar effects on a reduced scale should not be overlooked.

The toxicities of single salts to plant roots, and their amelioration by addition of calcium has been recognized now for almost a century. The literature on calcium requirements prior to 1938 was very adequately covered in a review by Kersting-Munster (1938). The first, and probably most interesting section of his paper covers the influence of calcium on root development. According to him, Stohman (1862) and Wolf (1864) were the first to approach the problem by use of water cultures. Wolf showed that the roots of Phaseolus multiflorus in single salt solutions of potassium, sodium, ammonium and magnesium soon became unhealthy and died. In single salt solutions of calcium however he found there was a stimulating effect on the root system. As early as 1875, Boehm recognized that addition of a very small amount of calcium salt removed the symptoms caused by other single salts. In his review, Kersting-Munster mentions three main theories derived from a great line of papers carrying on in the same theme up till 1927.

(1) Loew observed from microscopic examination of Spirogyra that the nucleus contracted when influenced by the toxic effect of salts. He also found that the same symptoms were obtained by application of sodium fluoride or sodium oxalate, both strong precipitating agents of calcium. He concluded that calcium was displaced from the nucleus.

(2) A second theory was that of Kisser (1925). He believed that the new growth was halted by a nutritional lack of calcium, and that the other cations dissolved the plasma membrane, after the nutritional deficiency had had its effect.

(3) A third theory was that of Hansteen-Cranner (1910, 1914, 1922), who, by microscopic observations showed that the nucleus was not the first organ to be affected, but that it was always affected after the destruction of the plasma membrane. He believed that the calcium acted primarily as a stabilizer of the plasma membrane, the cell being thereby protected against flooding by the other ions.

The extensive research of Mevius (1927) in general supports the Hansteen-Cranner concept. He tested three different types of plants:

(1) those which do not require calcium (or at least in very small amounts); (2) those for which calcium is necessary for normal growth, as represented by Zea mays; and (3) those which have a high demand for calcium (legumes). His experiments show that besides calcium, other factors such as pH, temperature, and other ion antagonisms may modify the effects of various solutions on root growth. He found that response of root growth to calcium was reduced by antagonism between magnesium and potassium, especially at low temperatures and over a narrow acid pH range. Pinus pinaster, which had the lowest calcium requirement, showed no depression of root growth in a calcium free solution containing magnesium and potassium, between pH 3.3 and 3.4, when compared to a similar calcium containing solution, both being carried for an eight month period. At higher pH some response was shown to calcium, especially at higher temperatures. The complete antagonism between potassium and magnesium on the root growth of Zea mays, occurred only over the pH range 4.4 to 4.6, and at low temperatures. The legumes in every case died without calcium, though the toxic effects of the solutions were least in acid reaction. A small amount of data showing a correlation between permeability and the toxic effects already noted was also presented.

In his literature review, Mevius (1927) quotes Hansteen-Cranner as saying that under the influence of calcium ions the roots grow to a great length, become thin, firmly and sharply outlined, snow-white to opaque in color and form many well developed branches and root hairs. Then he says that such a formation can occur in fresh moist air. This latter statement appears most interesting. It would appear that no immediate calcium deficiency symptoms occur in roots not in contact with other ions, thus showing the effect of calcium is indeed to protect the root from other ions. The fact that this protection is not forthcoming from calcium within the plant is also shown by some recent research using roots of barley seedlings

split between calcium carrying and calcium lacking solutions. There was no amelioration of the root damage in the calcium free solution, even though the plant was supplied internally with calcium from the other solution. However this does not prove that the calcium from one root ever reached the other. In fact Aisz (1952) reports in his review that calcium is absent in the sieve tubes and thus is not transported downward.

Although evidence points to the fact that the function of calcium in ameliorating the toxic effects of other salts is due to its stabilization of the plasma membrane, there is no doubt that it serves other purposes within the cell, and some of the symptoms might be confusing. Sorokin and Sommer (1929, 1940) found that the roots of Pisum sativum soon died in calcium lacking solutions, or solutions containing only minute quantities of calcium. They showed that an upset of normal mitosis in the root tip occurred. In their latter experiment (1940), the seedlings were dead after three weeks in all solutions studied. A solution containing 0.06 parts per million calcium had normal cell development after seven days, but after fifteen days the cell development was similar to those with no calcium, showing polyploid nuclei, bi-nucleate cells, constricted nuclei, and stages of amitotic division. The tissues were lacking in resistance to infection by micro-organisms, which penetrated the cells and accelerated the disintegration of the protoplasts. However, though the presence of 0.25 parts per million of calcium excluded the occurrence of cytological symptoms, the plants died. This would indicate that the immediate cause of death was not the aberration of mitosis, but some other more immediately important factor, and the mitotic upset might be a secondary effect, or it might represent an entirely different role of calcium in the plant.

Some other functions of calcium are its combination with the pectinates to act as a binding material in the middle lamella, and its combination with oxalate, acting possibly as a detoxifier.

THE COMPARISON OF DIFFERENT SALTS

Much of the early work on the toxic effects of excess salts has already been mentioned under the heading of "Calcium and Ion Antagonisms". This work was concerned with the effects of single salts in the pure state, and relatively small amounts of these salts were highly toxic. However, there was in fact inherent in the early work with pure salts, a deficiency of calcium, which is required in the exterior solution for stabilization of the plasma membrane, and within the cell for various functions. The reaction to other salts under these conditions can not be considered normal, and in any case, can have no practical application in the field where such extreme deficiency would scarcely ever exist. The modern trend has been to determine the reaction of plants to individual salts in combination with a complete nutrient solution, of as near an optimum combination as possible. Under such conditions, as has already been mentioned, the difference between the common salts is minimized when they are compared on the basis of isosmotic pressure. However, highly significant differences still occur, but the fact that the relative reactions of different ions may be quite different on different species, and also that different individuals have obtained different results makes generalization difficult.

For instance, in the comparison of chlorides and sulphates Hayward and Long (1942) found chlorides more toxic to peach trees than sulphates, at isosmotic pressures, and again Magistad et al (1943) state they found chlorides more toxic than sulphates to alfalfa. On the other hand most other research reviewed indicates sulphates to be more toxic than chlorides. This can be shown from the data of Eaton (1942) by plotting yields against freezing points (not done in the paper), data being presented for milo, alfalfa, cotton, tomatoes and sugar beets. Hayward and Spurr (1944) showed that sodium sulphate is more toxic than either sodium chloride or calcium

chloride to flax, the latter two salts being about equivalent. Gauch and Wadleigh (1944) compared the chlorides of sodium, calcium and magnesium, and the sulphates of sodium and magnesium for their effects on the growth of bean plants, and again sulphates were more toxic than chlorides at higher concentrations and also magnesium salts were more toxic than sodium or calcium. Hayward and Long (1941) compared the effect of equal osmotic pressures of sodium sulphate and sodium chloride on the growth, chemical composition and anatomy of tomato plants. Though the differences were not great, sulphates were consistently more toxic than chlorides. Determinations of the osmotic pressures of plant juices showed that the sulphates cause higher osmotic pressures than chlorides. They make the statement that the accumulation of sodium by the plant showed a close relationship to the amount of sodium present in solution, irrespective of anion. Considering this to be true, then it might be argued that the extra toxicity of the sulphates is caused by the higher amounts of sodium present at equal osmotic pressures. However, an examination of their graph relating concentrations of sodium in substrate and plant does indicate a considerably increased uptake of sodium from the sulphate, lending doubt that anything is proven here.

THE INFLUENCE OF pH ON PLANT GROWTH

As one feature of alkali soils may be pH, one must not overlook the possibility of the influence of pH on the plant. A vast literature has accumulated on the main aspects of the influence of soil reaction on plant growth, much of it being of a contradictory nature, and no attempt is made here to cover the field, but a few selected papers which appear pertinent will be mentioned. Brezeale and McGeorge (1932), using nutrient solutions, showed (1) that at a pH of 10 caused by sodium hydroxide, root growth can continue at a reduced rate; (2) that phosphate and nitrate absorption by plants is almost nil above pH 8, and (3) that the carbon dioxide added from

rotting manure or any other source will lower pH enough to permit normal absorption. McGeorge (1942) showed the effects of alkaline and calcareous soils on the uptake of phosphate, potassium and calcium as determined by Neubauer tests. A pH of 9 or over, as determined by 1:10 dilution, appeared to be definitely inhibitory to the uptake of calcium, potassium and especially phosphate. However, pH was noticeably effective only over the higher pH range, and when it was lower than 8.75, other factors such as CO₂ soluble calcium, phosphate and potassium appeared to be determining.

Returning again to the paper of Mevius (1927) on the effect of calcium ion on root growth, it can be seen that in the absence of calcium, pH may well be a determining factor affecting permeability and ion toxicity, but in the presence of calcium, variation in pH over a fairly wide range has little effect. However, there seem to be species differences in this respect. Wilde (1954) expresses some opinions on pH derived from observations and literature reviewed, and feels that the importance of pH variation to plant growth has been over emphasized in the past, especially in the correlation of observed, ecological phenomena to soil pH. This does not mean that the pH within a growing plant is not important. On the other hand, the cell itself is generally quite sensitive to pH changes, but the excellent buffering within the cells and the ability of plants to adjust the pH in their immediate environment by root respiration overrule the effect of external pH.

The general conclusions from these papers would indicate that pH itself is probably not the cause of toxicity in alkali soil, but it is quite possible that nutrient deficiencies, especially of calcium, potassium and phosphate may occur in these soils.

THE EFFECT OF CLIMATE ON SALT TOLERANCE

Ahi and Powers (1938) tested the germination of alfalfa and strawberry clover seeds in various dilutions of sea water at three different temperatures. Whereas at very low salt concentration there was little difference in germination between temperatures of 55°F and 70°F, when the salt concentration was increased to 6,000 parts per million, germination at the higher temperature was reduced to approximately half that at the lower, indicating an interaction between salt concentration and temperature. Magistad et al (1943) showed that the reaction of various species to salinity was different at different locations of divergent climatic conditions and altitude.

THE EFFECT OF SALINITY ON SEED GERMINATION

Ayers and Hayward (1948) mention that "crops growing in soil subject to salinization are frequently interspersed with numerous barren areas where salinity was sufficiently high at the time of planting to prevent seed germination". This indicates that the relative tolerance of crops at the time of germination and seedling establishment is highly important.

All workers are in agreement that there is a delay in the time required for germination, proportional to the salt concentration. It is quite possible that this delay in germination may render the seedling more susceptible to attack from soil micro-organisms. It might be suspected that the main factor affecting germination in saline solutions is the reduced water uptake due to the osmotic pressure of the solution. Rudolfs (1925) tried presoaking seeds in water before germinating on saline substrata but found no stimulation of germination.

There is a possibility that the year in which the seed was produced may affect its tolerance to salinity as shown by Gassner (1953).

His research was directed to the identification of different varieties of wheat by the maximum osmotic pressures of sugar solutions tolerated in germination. He found that besides varietal differences, there was the factor of the climate under which the seed had been produced, hot and dry seasons contributing to a higher tolerance.

Harris (1915) reported on seed germination tests in soil and sand cultures brought up to certain levels of salt, and maintained at certain moisture levels. He tested a large number of salts, including the sulphates, carbonates and chlorides of sodium, magnesium and potassium, and calcium chloride, all being compared on the basis of parts per million. When his data are converted to the osmotic basis of comparison there is good agreement between the salts in sand cultures. Because of cation exchange phenomena, not recognized at that time, the soil cultures were considerably less toxic to many of the salts used. There was severe to complete inhibition of germination of wheat over the range of 9 to 13 atmospheres osmotic pressure.

The paper of Rudolfs (1925) was the earliest reviewed in which the osmotic values of different salts were used in seed germination studies. Of the salts used potassium carbonate was the most toxic to germination. Peas, alfalfa, lupin and buckwheat were found more sensitive to salt than corn and wheat. Mulwani and Pollard (1939) carried out germination studies on salinized sand and soil cultures. Unfortunately tests were not carried out at sufficiently high concentrations to get an adequate view of the depressing effects of salt on germination. Their tests showed corn to be the most sensitive of the crops tested, while alfalfa and paddy were among the most tolerant. The addition of gypsum gave a strong amelioration of the toxic effects of the sulphates and chlorides of magnesium and sodium and of sodium carbonate. The ameliorating effect of calcium on seed germination has been shown by Albrecht (1941) in studies on the toxic

effects of fertilizers on the germination of tomato seeds.

FIELD TRIALS

Results from only a few field trials have been encountered in the literature, and the only one which will be quoted here is that of Forsberg (1953), as his work has a particular bearing on crops important in western Canada. Field tests were made on naturally occurring saline areas, using long narrow plots seeded into an increasing salinity gradient. The criterion of the tolerance was the distance into the saline area that the different crops survived. Using the above method in conjunction with greenhouse studies, it was concluded that tall wheatgrass and slender wheatgrass were among the most tolerant species tested, the tall wheatgrass being better than slender wheatgrass where water logging was a factor.

GERMINATION EXPERIMENTS

METHODS

Germination and seedling growth studies were carried out on purified sand in small, sub-irrigated dishes. The sub-irrigated dishes were evolved after conclusion of various preliminary experiments, using blotters moistened with the required salt solutions either by pipette or by wick from a reservoir.

A large number of preliminary experiments comparing different salts, different species and nutrients were then carried out using uncovered metal dishes painted with Glyptol, an electrical paint. An illustration of this early type of equipment is shown in Plate I(b). It was found that there was considerable variability between tests and also it was found that there was a great difference in the amount of water needed to maintain the proper level in the reservoir. These two observations indicated that humidity was an important factor, probably because of its effect on evaporation and concentration of the salt solutions, despite the fact that all experiments were conducted in cabinets supplied with an open surface of water in the bottom.

It was felt that lids on the dishes would maintain the humidity corresponding to the salt concentrations being used, which is exactly analagous to the situation in the soil, in which the humidity of the soil atmosphere is affected by the osmotic pressure of the soil solution. In some preliminary experiments seeds were actually germinated in an atmosphere of about 100 percent relative humidity, without any direct contact with liquid water. Thus it is fundamentally important to have a humidity maintained which will correspond to the salt being used. It was thought that by the time the leaves reached the lids the roots would be developed enough

to permit removal of the lids. Thus differences in humidity would not affect the percentage germination and plant growth would be allowed to continue normally.

Forty Petri dishes 20 millimeters deep by 100 millimeters in diameter, each with a glass tube drain of 2 millimeters inside bore and 20 millimeters long fused to the bottom, were obtained. The lids were unmodified. Six-ounce dispensing bottles requiring size 1 rubber stopper were used as reservoirs. Each stopper had two holes, one to take the tube leading to the Petri dish and the other to take a tube for supplying pressure to cause irrigation. The 20 millimeter tube of the Petri dish was forced half way through the stopper, and another tube about 60 millimeters long was pushed in to meet it from the other side. By this means a flexible union of the tube leading from the solution to the Petri dish was made, which greatly reduced the breakage hazard. Pressure to cause irrigation was obtained simply by expiration. An illustration of this equipment appears in Plate I(c).

The use of sand as a substrate is a much used practice, and the following points are thought to be pertinent to its use in these studies: (1) sand has practically no cation exchange property, and thus will not affect the composition of the salt solution passing through it by cation exchange phenomena, (2) the moisture retained after an irrigation is held relatively loosely by the sand, so that the total moisture stress against which the moisture is acquired by the seed can be assumed to be equal to the osmotic pressure of the solution, (3) the sand serves as a reservoir of moisture for the seeds between irrigations, there being a capillary movement from the interior to the surface as moisture is taken up by the seed, (4) the sand serves as an aerated medium into which roots can grow after germination.

Ottawa white sand was used. It was screened to a size less than 1 millimeter and large enough not to pass through double cheesecloth which was used to retain the sand in the bottoms of the dishes. Between experiments the sand was washed first with concentrated hydrochloric acid, then with tap water till excess acidity was removed, and then washed with distilled water till free of chloride ion. It was then dried in an oven at 105°C. An occasional soaking of the sand with a sulphuric acid, dichromate solution was used to remove organic matter which might have accumulated from roots.

Mold growths, generally of Penicillium or Rhizopus species, were observed to infect seed cultures which were delayed in germination for periods of a week or more due to high salt concentrations. These molds did not apparently affect the germination of the grass seeds excessively, though in some instances were thought to have affected the germination of legumes. With regular washing of sand in acid and drying at 105°C, there is no doubt that the source of contamination was usually the seed. It was considered undesirable to use surface sterilization on the seed because of possible effects on permeability.

In earlier experiments solutions were made up from single salts, the osmotic pressures being calculated by means of the gas equation. In later experiments, where more complicated solutions were being used, graphical determinations of the osmotic pressure were made by using graphs similar to those included in the chart inside the back cover. The compositions of the base nutrient solutions used are shown in Table VII. The concentration of single salts used to bring up the osmotic pressures are generally included in the tables of the experiment involved.

When time and equipment were available, solutions were checked

at the commencement of experiments and at the conclusion of experiments for pH, using a Beckman pH meter; osmotic pressure, using the freezing point depression, and conductivity using a Soil Solu Conductivity Bridge. Comments on the freezing point method for determining osmotic pressure are included in the Appendix.

STATISTICAL TREATMENT

In preliminary work in which the bounds of possibilities were being explored statistical treatment of the data was not necessary. Quite early in the work it was recognized that testing a number of salts or species at one concentration alone was not effective, unless it was known before hand that the concentration used would reduce germination to about the 50 percent level. Once the concentrations causing such reduction were known it might well be possible to test a number of varieties of a species for instance, and do analysis of variance to determine differences between them at the one concentration. However, before such work could be carried out the response of the species over a range of concentrations affecting germination from a maximum to low germination should be known. As the number of culture dishes was limited, and it seemed important to get some practical information as quickly as possible, in all early experiments a range of concentrations was used without duplication. When it was desired to test different species or kinds of salt over a range of osmotic concentrations, like concentrations were grouped together, allowing their removal as replicates. In such instances it was impossible to test for the significance of the interaction, treatment x concentrations. Where only paired treatments were compared the t test was applicable. In the latest experiments, using the covered dishes, it was possible, by dividing each dish to run duplicates. Thus two replicates were supplied as far as biological variation was concerned. In order to obtain two more replicates

the complete experiment was repeated. Statistically speaking, it might be legitimate to remove variation between experiments, but not between duplicates.

The culture dishes were conveniently held in racks of six and it was possible to pair the required cultures. The racks were rotated daily within the environment.

PLANT MATERIAL

In order to eliminate the constant repetition of scientific names, and to define the common names of species used, a listing is made here of the species used throughout the work, both in the sections on Germination Experiments and on Introduction Nurseries. Reasons are also given for the inclusion of the species in the tests.

Alfalfa (Medicago media) is one of the most valuable producers of quality hay on irrigated land in southern Alberta. Its wide spread use necessitates a knowledge of its limitations on saline soils. The variety Ladak is at present recommended as it is a partially wilt tolerant variety.

White blossom sweet clover (Melilotus alba) is known to be capable of high production on saline land once it is established, partly because of its tolerance to water logging.

Strawberry clover (Trifolium fragiferum) is a legume reported to have fairly high tolerance to salinity.

Reed canarygrass (Phalaris arundinacea) is an excellent grass for areas subject to periodic flooding, but it is not tolerant to high salinity. A knowledge of its limits of tolerance would be most desirable.

Tall fescue (Festuca arundinacea) is a pasture grass known to possess high tolerance to excess water and to have some tolerance to salinity. Though its late starting in the spring may indicate a tendency to winter injury, no killing has been observed in plots since testing started. The

varieties Alta, K31, and Goar have been used in tests. It may be interesting to note that the name Alta is derived from the term "tall".

Tall wheatgrass (Agropyron elongatum) is a relatively new grass introduced from Asia. It has a high tolerance to salinity and water logging, but is very coarse in growth, so cannot be considered a high quality forage.

Slender wheatgrass (Agropyron trachycaulum), known also as western ryegrass, is noted as a tolerant species for saline land under dry conditions, but has a tendency to be short lived. The variety Primar has been used in these tests.

Intermediate wheatgrass (Agropyron intermedium) is a strongly creeping grass useful for soil conservation purposes. The strain Amur has been reported tolerant to saline soils. Both the commercial strain and the Amur strain were tested.

Agropyron pungens, an unnamed wheatgrass native to coastal regions, has been reported useful for saline areas.

Russian wild rye (Elymus junceus) is a new grass useful for arid regions and shows some tolerance to salinity.

Nuttall alkali grass (Puccinellia aeroides) is an native halophyte which appears very tolerant to salinity, but apparently this tolerance is closely related to certain moisture conditions not fully understood. It is generally hard to establish artificially.

Orchard grass (Dactylis glomerata) is a highly productive pasture grass used in southern Alberta and appears particularly susceptible to soil salinity so is useful as a check.

PRELIMINARY EXPERIMENTS

In the earliest experiments single salt solutions were used at concentrations of 0, 1, 8 and 15 atmospheres osmotic pressure. Comparisons

were made of the salts, sodium chloride and calcium chloride, and they were found to be approximately equivalent in their effects. Then a number of species were tested at various osmotic pressures of sodium chloride. In Table II are summarized the results of two experiments comparing the tolerance of tall wheatgrass, Ladak alfalfa, strawberry clover and white blossom sweet clover. Tall wheatgrass proved to be the most tolerant, giving a high percentage of germination at the 15 atmosphere level. The legumes tested gave little or no germination at that level but germinated well at the 8 atmosphere level. Statistical analysis of the data show the differences between species and between concentrations to be highly significant.

The equipment was being evolved during preliminary experiments, and a conception of approximate reactions of a large number of species was obtained. The data are not considered accurate enough to present here, but they were very useful in aiding the design of subsequent experiments.

THE RELATIVE TOLERANCES OF CHLORIDE AND SULPHATE

Using uncovered, sub-irrigated sand cultures, the species, tall wheatgrass, Alta fescue and reed canarygrass were tested with concentrations of sodium chloride and sodium sulphate which were thought should be critical to the germination of each species. The cultures were maintained at 21°C in a Mangelsdorf germinator. It was noticed in this experiment that germination percentages were in general much lower than had been expected, except possibly those of tall wheatgrass. On the basis of later research it is known that the absence of calcium was the cause of this poor growth. It had previously been thought that the seed itself would contain enough nutrients for the seedling, so no calcium was added. Alta fescue appeared particularly susceptible to the calcium deficiency and root growth was very short, the roots turned black and eventually died. Results of this test are recorded in Table III.

TABLE II. The Effect of Increasing Osmotic Pressures of Sodium Chloride on the Germination Percentage of Four Forage Species, as Determined in Uncovered Dishes, Sub-irrigated from Small Reservoirs. Results are expressed as Percent of Check.

Species	Osmotic Pressure, Atmospheres			Species Average
	1	8	15	
Alfalfa	94	63	1	54
Sweet Clover	82	68	4	51
Strawberry Clover	104	46	0	50
Tall Wheatgrass	95	94	81	90
Concentration Average	94	68	22	

Least Significant Difference Applicable to:

Species Average at 5% Level	20.9
Species Average at 1% Level	31.6
Concentration Average at 5% Level	18.1
Concentration Average at 1% Level	27.4

TABLE III. The Effect of Increasing Osmotic Pressures of Sodium Chloride and Sodium Sulphate in Uncovered, Sub-irrigated Sand Cultures, on the Germination and Leaf Growth of Three Forage Species.

Osmotic Pressure Atmospheres	Tall Wheatgrass				Alta Fescue				Reed Canarygrass			
	Percent Germination		Leaf Height Centimeters		Percent Germination		Leaf Height Centimeters		Percent Germination		Leaf Height Centimeters	
	NaCl	Na ₂ SO ₄	NaCl	Na ₂ SO ₄	NaCl	Na ₂ SO ₄	NaCl	Na ₂ SO ₄	NaCl	Na ₂ SO ₄	NaCl	Na ₂ SO ₄
8						47*		0.27*	19	17	0.83	0.71
9						27*		0.27*	9	2	0.55	0.12
10					35	2	0.41	0.00	5	2	0.50	0.00
11					14	1	0.25	0.00	3	0	0.50	0.00
12					4	1	0.18	0.00	2	0	0.12	0.00
13	88	72	2.8	1.6	6	0	0.16	0.00				
14	86	74	2.4	1.3	1	0	0.25	0.00				
15	83	65	1.8	0.7								
16	82	58	1.4	0.4								
17	85	50	1.4	0.7								

* Not included in Statistics

Level of Significance	1%	50%	1%	1%
(t test)				

In both percent germination and length of leaf growth, sodium chloride was much less toxic than sodium sulphate. The possibility that this might have been caused by miscalculations of the osmotic pressures was checked by determining the freezing point depression on some of the solutions, and there was found to be a reasonably good check with the calculated value.

CALCIUM AMELIORATION OF TOXICITY OF OTHER SALTS

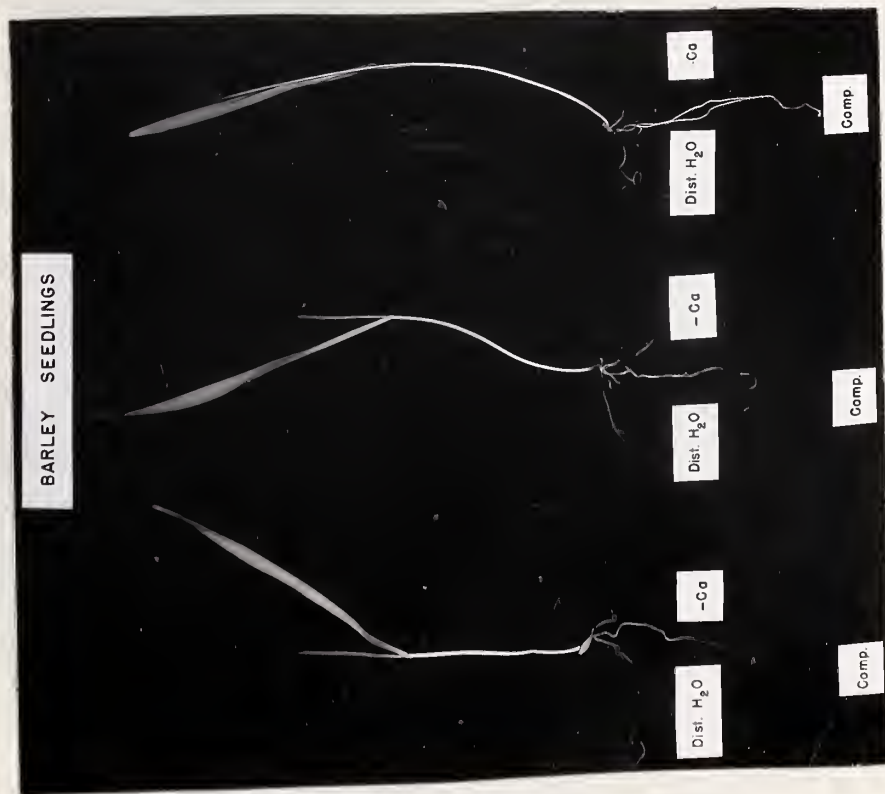
In an effort to prove conclusively that calcium is an important factor in the germination of seeds in salt solutions of higher osmotic pressures, an experiment was designed in which tall wheatgrass, Alta fescue, reed canarygrass and alfalfa were tested in dishes containing a series of increasing concentrations of sodium chloride in which calcium-free and calcium containing solutions were paired. Tall wheatgrass was tested over the range seventeen to twenty-one atmospheres osmotic pressure, while all other species covered the range six to ten atmospheres. The shortage of dishes is the reason for not covering the full range of tolerance of the species. The experiment was carried on in an unlighted incubator at 21°C. A summary of results appears in Table IV, and an illustration in Plate I(b).

Despite the fact that the osmotic pressure of the calcium containing solutions was somewhat greater than that of the calcium-free, caused by the addition of calcium, germination percentage and growth were much greater in the calcium containing solutions. It will be noted, however, that the germination was somewhat less in comparison with the corresponding cultures of the previous experiment. There are probably two factors which were involved here: (1) there may have been some calcium contamination in the previous experiment or (2) more probably the humidity in the atmosphere of the latter test was much lower than in the previous.

It was felt that the increased toxicity of the sodium sulphate

TABLE IV. The Effect of Addition of Calcium Chloride on the Toxicity of Sodium Chloride to the Germination and Seedling Growth of Various Forage Species, Determined in Uncovered, Sub-irrigated Sand Cultures at 21°C.

Osmotic Pressure Atm.	Reed Canarygrass				Alta Fescue				Alfalfa				Osmotic Pressure Atm.		Tall Wheatgrass			
	Percent Germ. -Ca +Ca	Leaf Height Centimeters -Ca +Ca	Percent Germ. -Ca +Ca	Leaf Height Centimeters -Ca +Ca	Percent Germ. -Ca +Ca	Leaf Height Centimeters -Ca +Ca	Percent Germ. -Ca +Ca	Leaf Height Centimeters -Ca +Ca	Percent Germ. -Ca +Ca	Leaf Height Centimeters -Ca +Ca	Percent Germ. -Ca +Ca	Leaf Height Centimeters -Ca +Ca	Osmotic Pressure Atm.		Percent Germ. -Ca +Ca	Leaf Height Centimeters -Ca +Ca	Percent Germ. -Ca +Ca	Leaf Height Centimeters -Ca +Ca
6	2 10	0.75 1.02	40 92	0.98 2.49	0 20	0.00 0.88	17	19 23	0.14 0.05									
7	3 13	0.66 0.40	24 87	0.79 2.33	0 27	0.00 1.53	18	7 28	0.00 0.25									
8	1 10	0.00 0.50	15 83	0.40 1.44	0 19	0.00 0.74	19	3 16	0.25 0.27									
9	3 4	0.33 0.12	8 67	0.50 1.37	0 10	0.00 0.50	20	2 11	0.00 0.38									
10	1 2	0.25 0.50	1 53	0.25 0.88	0 4	0.00 0.43	21	2 0	0.00 0.00									
T Value	25.0	1.05	18.9	6.25	3.98	4.18		6.72	2.20									
Level of Significance (t test)	1%	N.S.	1%	1%	2%	2%		1%	2%						1%			N.S.

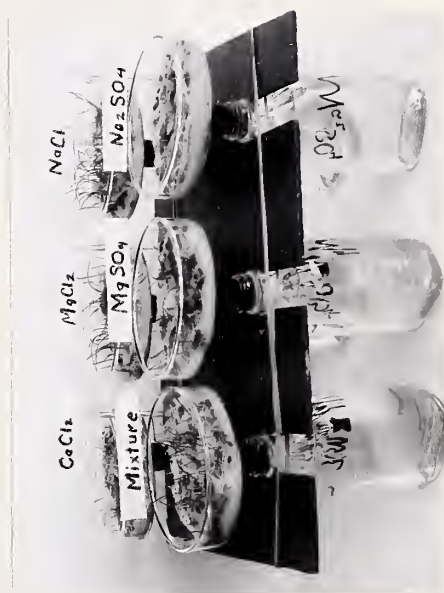


(a) The effect of calcium deficient distilled water compared to calcium deficient base nutrient solution on split barley roots being supplied calcium through another root in calcium carrying nutrient solution.



(b) The ameliorating effect of calcium on the toxicity of NaCl to germinating seeds of Alta Fescue. Front Row - calcium lacking. Back Row - calcium containing.

(c) The effect of different salts at 16 atmospheres osmotic pressure on the germination of Alta Fescue.



solutions over the sodium chloride already reported, might have been caused by the higher concentrations of sodium in the former at equal osmotic pressures. The classical explanation of toxicities of salts is that the cation is more or less liquifying in its effect on the plasma membrane. Sodium is supposed to be high in its liquifying effects and for that reason is more toxic. The increase in sodium supplied by sodium sulphate at equal osmotic pressures would in this manner cause an increase in toxicity. On the other hand calcium ion is supposed to ameliorate the toxicities of the liquifying ions by its dehydrating effect on the plasma membrane.

In the presence of calcium then, one might expect that the differences between the toxic effects of sodium chloride and sodium sulphate at equal osmotic pressures might be minimized. An experiment was designed in which equal osmotic pressures of sodium chloride and sodium sulphate were compared, each in the absence and in the presence of calcium. In order to eliminate the complication of the absence or presence of specific anions, a small amount of sodium sulphate was added to the sodium chloride solution, and a small amount of sodium chloride was added to the sodium sulphate solution. Calcium was added as the sulphate to the sodium chloride solution, and as the chloride to the sodium sulphate solution. In this manner the same amount of chloride occurred in the sodium sulphate solutions, both with and without calcium, and likewise the sodium chloride solutions contained the same amounts of sulphate both with and without calcium.

The results of this experiment are summarized in Table V. Again as in the previous experiment the addition of calcium caused a highly significant increase in germination percentage. However, there was no indication of any relative change in the toxicities of sodium chloride as compared to sodium sulphate. The relative length of root growth between calcium containing and calcium lacking solutions is very striking, the

TABLE V. The Effect of Addition of Calcium on the Toxicities of Sodium Sulphate and Sodium Chloride, to the Germination, Leaf Growth and Root Growth of Alta Fescue (*Festuca arundinacea*), Determined in Uncovered, Sub-irrigated Sand Cultures at 21°C. Average of Two Replicates.

Osmotic Pressure Atmospheres	Molal Concentration and Salt		pH		Percent Germination	Average Length of Tops (cm)	Average Length of Roots (cm)
	NaCl	Na ₂ SO ₄	Initial	Final			
8	0.171	0.01	6.4	4.8	72	1.08	0.12
9	0.195	"	6.4	4.6	48	0.64	0.12
10	0.218	"	6.2	5.0	38	0.55	0.10
Average			6.3	4.8	52.7	0.76	0.11
8	0.137	0.02	6.2	5.2	40	0.46	0.10
9	0.179	"	6.7	5.2	20	0.26	0.14
10	0.152	"	6.2	5.2	7	0.23	0.10
Average			6.4	5.2	22.3	0.32	0.11
8	0.185	0.01	6.9	4.9	78	4.33	1.46
9	0.209	"	6.6	4.7	74	4.67	1.78
10	0.22	"	6.3	5.2	75	3.13	1.44
Average			6.6	4.9	75.7	4.04	1.56
8	0.152	0.01	5.8	5.0	74	2.94	0.94
9	0.173	"	5.8	5.0	37	2.08	0.88
10	0.194	"	6.4	5.3	28	1.35	0.65
Average			6.0	5.1	46.3	2.12	0.82

Levels of Significance between: Salts (NaCl and Na₂SO₄) 1% N.S.
Calcium Carrying and 1% 1%
Calcium Deficient 1% N.S.
Concentration

former being almost ten times that of the latter in the case of the sodium sulphate solutions, and fifteen times in the sodium chloride solutions.

In some other cultures the quantities of sodium occurring in isosmotic sodium chloride and sodium sulphate solutions were balanced by addition of sucrose to the sodium sulphate solution, using a molality of sodium sulphate exactly half that of sodium chloride. However, trouble was incurred by fermentation of the sucrose carrying solutions and toxicity was far greater in them, making the results untenable. This approach has been discarded till such time as a technique of sterile culture has been developed. It might be noted here that Uhvits (1946) found sucrose solutions less toxic to germinating alfalfa seeds than salt solutions of equal osmotic pressures.

In some of the author's earlier experiments the observation was made that seeds germinated well on distilled water in the absence of calcium. It has also been noticed from pictures by Gauch (1943) that bean plants grew better on distilled water culture than on base nutrient solution in absence of calcium. This phenomenon is a result of the toxic effects of other ions in the absence of calcium, while in distilled water the other ions are not present.

In order to illustrate this point further, roots of barley seedlings were divided in three directions into solutions of base nutrient with and without calcium, and distilled water. The results of this test are illustrated in Plate I(a), from which it will be noticed that though root growth of the complete nutrient solution was by far the best, in every instance the distilled water was somewhat better than the calcium deficient nutrient solution. Another point illustrated here is that a plant obtaining calcium can still suffer severe calcium deficiency

symptoms in roots in contact with calcium lacking solution. However, the fact that calcium is available does not necessarily mean that it is translocated back down to the roots in the calcium deficient solution.

THE EFFECT OF TEMPERATURES ON GERMINATION IN SALINE CULTURES

Reports in the literature have shown that temperatures affect the tolerance of different species to salinity and it was thought desirable to observe if similar results would be obtained, using the sub-irrigated equipment, where osmotic pressure of the solution could be well controlled. A Mangelsdorf germinator was kept in a room which was normally at temperatures of 26°C to 29°C and was adjusted to maintain the temperature of 29.4°C (85°F). Two incubators were placed in a room the temperature of which was maintained at 12.8°C (55°F) and the temperature of one of the incubators was adjusted to 21.1°C (70°F) while the other was allowed to remain at 12.8°C (55°F). All incubators were kept in darkness and all had trays of free water in the bottom to maintain humidity. The species K31 tall fescue was tested over a range of eight to twelve atmospheres osmotic pressure and the species reed canarygrass over a range of six to ten atmospheres in increments of one atmosphere. Checks were run on both species in distilled water and calcium chloride at one atmosphere osmotic pressure at each temperature. The germination percentages obtained from this experiment are recorded in Table VI. The general results of the experiment show that reed canarygrass germinated best at the higher temperature while K31 fescue germinated best at the lower temperature. Unfortunately, it was apparent early in the experiment that the humidity in the 21.1°C incubator was excessively low as indicated by the large amounts of water that had to be added to the reservoirs to maintain the solution level. The germination of Alta fescue (of the same species as K31) in a previous experiment was 83 percent for instance, at eight atmospheres

TABLE VI. The Effect of Temperature and Salt Concentration on the Germination of K31 Fescue (*Festuca arundinacea*) and Reed Canarygrass (*Phalaris arundinacea*).

Concentration		T E M P E R A T U R E S							
		55°F		70°F		85°F		Average	
		Reed Canary	K31 Fescue	Reed Canary	K31 Fescue	Reed Canary	K31 Fescue	Reed Canary	K31 Fescue
Distilled Water		12	58	31	58	53	21	32	48
CaCl ₂	NaCl								
1 atm.	0 atm.	10	62	23	52	45	28	26	47
1 "	5 "	4		7		18		10	
1 "	6 "	1		2		18		7	
1 "	7 "	1	41	0	28	7	10	3	26
1 "	8 "	0	29	1	27	2	13	1	23
1 "	9 "	2	34	2	27	3	4	2	22
1 "	10 "		30		15		5		17
1 "	11 "		18		10		6		11
Average		4	35	9	31	21	12	12	28

osmotic pressure at 21°C compared to 28 percent of K31 fescue in this experiment, indicating the extreme effect of humidity on germination in this case. Thus it can be presumed that the 21.1°C (70°F) data are excessively low and would probably have been better at that temperature than either extreme had it not been for the humidity factor.

It was also noted that germination was fastest at the highest temperature and slowest in the lowest temperature, there being for instance, a seven day delay in the commencement of germination of reed canarygrass in distilled water at the lowest temperature as compared to the highest. It was also noted that some deformation of the leaves of K31 fescue occurred on breaking through the coleoptile at the lowest temperature.

THE COMPARISON OF DIFFERENT SALTS USING COVERED DISHES

On the basis of previous experience already reported, covered, sub-irrigated culture dishes were obtained. The first experiment conducted with this equipment was one of comparison of different salts including the chlorides of sodium, calcium and magnesium, and of the sulphates of sodium and magnesium. The species Alta fescue was used for this experiment. A complete nutrient solution of one atmosphere osmotic pressure was used as a base, the composition of which appears in Table VII. Unfortunately in making up the solutions there was a failure to take into account the water of hydration of the salts which at higher osmotic pressures made considerable difference to the concentrations of salts having large amounts of water of hydration. However, in plotting the curves the corrected values were calculated so no error was thereby incurred. However, in statistical analysis it was necessary to make the assumption that the originally calculated values were the actual values. As it happened such an assumption tended to decrease the possibility of significance, therefore putting higher confidence in the values actually obtained. It was found possible to run

TABLE VII. Composition of Base Nutrient Solutions Used in the Three Experiments Recorded in Tables VIII, IX and X, Concentrations Being Those of the Final Solution.

Salt	Molal Concentration Applicable to Table VIII	Molal Concentration Applicable to Table IX	Molal Concentration Applicable to Table X
NaCl	0.0020	0.0020	0.0020
MgSO ₄	0.0020	0.0020	0.0020
CaNO ₃	0.0100	0.0100	0.0100
KH ₂ PO ₄	0.0050	0.00225	0.00225
K ₂ HPO ₄	-	0.00008	Titrated to pH 6.0 (amount varied for each culture)
NaOH	0.0022		
Estimate Osmotic Pressure at 21°C	0.99	0.90	Approximately 1.0 atmospheres
pH Range of Final Solution at Start of Experiment	5.20 to 4.26	6.01 to 5.53	6.00

Micro Elements were added at rate of 1 cc of the solutions (1) and (2) below, per liter of final solution.

Solution (1) 2.36 gm H₂PO₃; 1.31 grams MnCl₂; 0.23 grams ZnSO₄; 0.05 grams CuCl₂ per liter.

Solution (2) 5 grams FeCl₃.6H₂O and 5 grams tartaric acid per liter.

duplicates in each culture dish. The dishes were held together in racks of six, each rack holding each of the five salts at any one concentration plus a check of base nutrient solution. It was thus impossible with the forty dishes available and six treatments at each of six concentrations to have more than one dish for each treatment. Thus to obtain replication it was necessary to repeat the experiment. The experiment was carried out in a glass topped cabinet, diffused sunlight being the source of light. A temperature of $21^{\circ}\text{C} \pm 2^{\circ}\text{C}$ was used, and the experiment was run for sixteen days. In obtaining germination data only those seeds were counted which produced visible leaf blades, and the average length of leaf blade was obtained by measurement of each individual leaf blade and dividing by the number of seeds germinated. The total dry weight of tops produced in each culture was also determined and these were divided by the number of seeds germinating in order to obtain the average dry weight per seedling.

The osmotic pressures of the solutions used were checked initially and then after completion of the experiment by the freezing point method. Initial and final pH determinations were also made. Results of this experiment are recorded in Table VIII and graphical presentations are shown in Figures I and II.

Before discussing the relative toxicities of the salts, some of the general concepts illustrated in Figure II will be explained. The curves in Figure II are simply derived from the averages of all salts reported in Table VIII, being converted to percent of check to give a common basis of comparison. Considering first the percent germination curve, it is obvious, since the germination criterion gives yes or no type of data, and that if all seeds in a lot were identical in their reaction to salt concentrations, the germination of all seeds would be inhibited at identically the same concentration, and the curve would consist of a vertical line at

TABLE VIII. The Osmotic Pressures of Salt Solutions as Calculated and Determined by the Freezing Point, and their Effects on the Germination and Seedling Growth of Alta Fescue (Festuca arundinacea).

Salt and Concentration Moles/l,000 g H ₂ O	Calculated Osmotic Pressure	Osmotic Pressure by Freezing Point		pH		Percent Germination	Average Leaf Length cm.	Dry Matter Produced Per Culture (mg)
		Initial	Final	Initial	Final			
NaCl	6.00			4.70	5.90	83.0	7.70	
	8.00		8.15	4.72	5.96	81.5	6.21	54.4
	10.00	9.52	10.65	4.69	5.80	79.2	4.58	42.1
	12.00	11.00	12.28	4.69	5.88	72.8	1.42	35.1
	14.00	13.90	13.92	4.85	5.84	60.8	1.42	21.5
	16.00	15.92	16.00	4.85	5.75	45.5	1.15	9.2
Na ₂ SO ₄	6.00			4.88	6.54	81.0	7.88	
	7.92			4.92	6.39	75.8	5.50	48.5
	9.78	9.70	10.60	4.66	6.41	70.0	4.46	38.2
	11.71	11.85	11.91	4.88	6.12	58.2	3.04	24.4
	13.54			5.00	5.89	20.0	1.10	3.7
	15.38			5.01	5.96	4.2	0.72	0.5
MgCl ₂	6.00			4.30	5.94	80.0	7.46	
	7.95		8.35	4.34	5.63	78.5	5.60	49.2
	9.92	9.29	10.13	4.28	5.69	73.0	4.10	37.3
	11.80	11.10	11.61	4.23	5.58	66.5	3.14	30.2
	13.73	13.90	13.80	4.42	5.21	59.5	1.82	16.8
	15.65	15.23	16.10	4.30	5.00	24.2	1.24	4.6
MgSO ₄	6.00			4.54	5.88	82.0	7.04	
	7.78		8.35	4.64	5.70	74.0	5.00	43.7
	9.54	9.29	10.74	4.59	5.66	68.2	4.10	36.6
	11.42	11.08	11.08	4.54	5.50	65.0	2.49	22.1
	13.22	13.60	13.84	4.70	5.22	43.8	1.37	10.4
	14.93	14.50	15.88	4.69	5.20	13.5	0.65	1.7
CaCl ₂	6.00			4.40	5.05	78.0	6.34	
	8.00		8.40	4.42	5.17	64.2	4.76	32.4
	10.00	9.04	10.90	4.39	4.95	60.0	3.23	23.2
	12.00	11.50	12.31	4.36	4.89	46.2	1.63	12.2
	14.00	14.68	14.62	4.40	4.93	22.2	0.88	2.1
	16.00	16.52	17.08	4.40	4.82	6.0	0.31	0.5
Least Significant Difference at 5% Level for Salts x Concentrations							9.4	0.36
Least Significant Difference at 1% Level for Salts x Concentrations							12.6	0.50

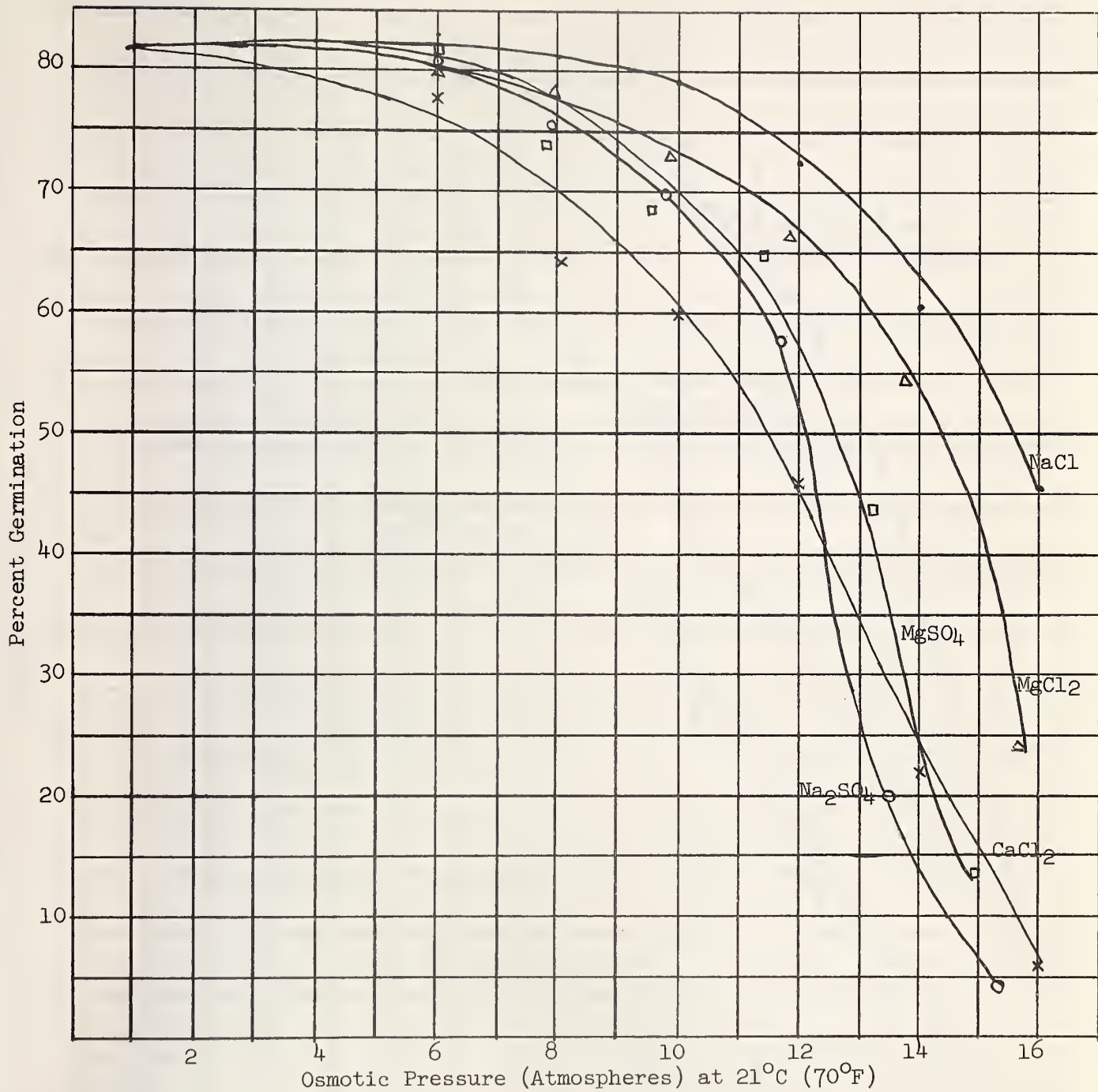


FIGURE I. The Effect of Increasing Osmotic Pressures of the Chlorides of Sodium, Calcium and Magnesium, and of the Sulphates of Sodium and Magnesium on the Germination Percentage of Alta Fescue (Festuca arundinacea)

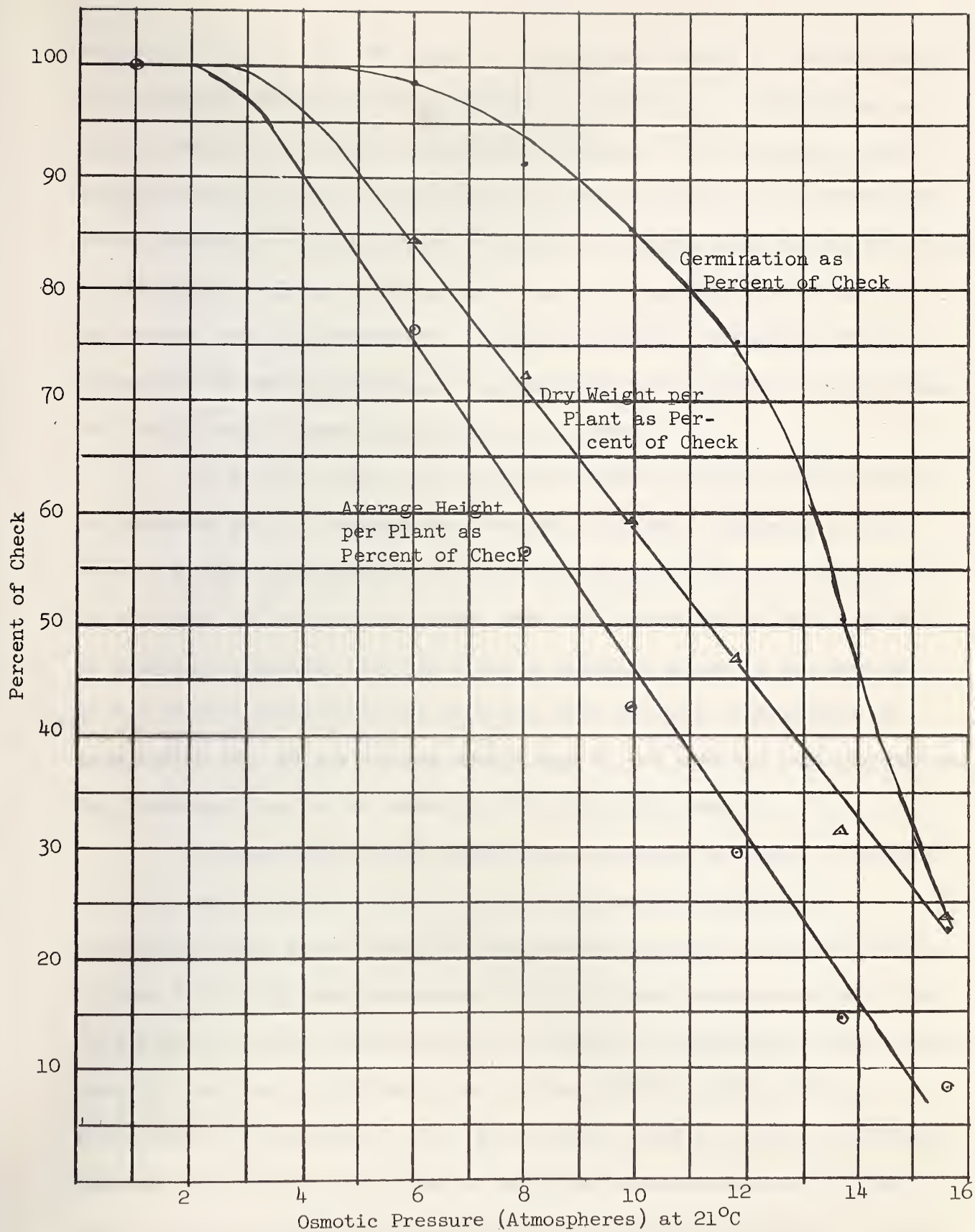


FIGURE II. The Effect of Increasing Osmotic Pressures on Germination Percentage, Dry Matter per Seedling and Length of Leaf per Seedling of Alta Fescue (*Festuca arundinacea*), all expressed as a Percentage of Check.

the cut-off point. The "S" shape of the curves obtained is then the result of biological variation, and the greater the biological variation the more gradual would be the slope of the curve obtained. On the basis of these considerations, it can also be seen that the flex point of the germination curve represents the reaction of the population mean, and thus the concentration at that point is critical. Also the point generally occurs at the 50 percent level of germination. Thus the concept is proposed that the concentration causing reduction of germination to 50 percent of check would be a useful way of summarizing this type of data.

It will be noted that the growth curves in Figure II are linear in shape and this is in agreement with other reports. However, it will also be noted that the curves do not pass through the origin. This might be explained by the fact that there were two factors affecting the growth of seedlings obtained: (1) the delay in moisture uptake by the seed due to the osmotic pressure of the solution, thus delaying commencement of germination and (2) the reduced growth rate of the seedling once germination had commenced, due to the osmotic pressure and salt used.

Returning now to the comparison of salts illustrated in Figure I, it can be seen that the sulphates of both sodium and magnesium are considerably more toxic than their respective chlorides to the germination of *Alta fescue*. Whereas magnesium chloride appears considerably more toxic than sodium chloride, the sulphates of sodium and magnesium have the reverse order if anything, though there may be some doubt that these latter differences are significant. Calcium chloride appears to have a different type of curve than the other salts indicating that possibly a different genetical factor is involved in the tolerance. Calcium appears to be one of the more toxic ions.

Utilizing the above suggested method of reporting the concentrations causing a reduction in germination to 50 percent of check, the results of the preceding experiment can be summarized as follows. The germination of Alta fescue was reduced to 50 percent of check by solutions of 16.3 atmospheres of sodium chloride, 15.2 atmospheres of magnesium chloride, 13.3 atmospheres of magnesium sulphate, 12.4 atmospheres of sodium sulphate and 12.4 atmospheres of calcium chloride, all salts being in combination with a base nutrient solution.

It will be noted from Table VIII that pH was not entirely constant between salts in the experiment just discussed and although the fact that sodium sulphate, the most toxic salt, had a pH almost identical to that of sodium chloride, the least toxic salt, would indicate that pH is not a very important factor, some doubt might remain as to the importance of pH. Again it will be noted that the salts were not compared at exactly equal osmotic pressures, therefore another experiment was begun in which different salts were compared, the solutions being adjusted accurately to 16 atmospheres osmotic pressure and pH 6.0. The biological material was again Alta fescue and besides the salts in the previous experiment, there was an extra treatment consisting of an equimolar mixture of magnesium sulphate and sodium sulphate. Time was available for completion of only two replicates of this experiment, data being recorded in Table IX. In general results are in excellent agreement with the previous experiment, there being somewhat of an increase in the germination percentage with calcium chloride, magnesium chloride and magnesium sulphate. In this experiment germination was continued for twenty-one days instead of the sixteen of the other experiment, and that is probably the reason for the discrepancy. There is apparently some indication of an antagonism between sodium and magnesium as the mixture proved less toxic than either salt alone. An illustration of this experiment appears in Plate I(c).

TABLE IX. The Effects of the Sulphates and Chlorides of Magnesium and Sodium, of Calcium Chloride and of a Mixture of Sodium and Magnesium Sulphates, with Base Nutrient Solution, All at an Accurately Adjusted Osmotic Pressure of 16 Atmospheres, and pH of 6.0, on the Germination of Alta Fescue (Festuca arundinaceae).

Salt Used	Moles of Salt Added to Base Solution of 1 Atmosphere		Rep. I	Rep. II	Average
	Calculated	Used			
NaCl	0.3385	0.3385	41	47	44
Na ₂ SO ₄	0.3001	0.3001	9	4	6
MgCl ₂	0.2304	0.2304	35	40	38
MgSO ₄	0.5822	0.5822	17	30	24
CaCl ₂	0.2401	0.2260	20	22	21
MgSO ₄ and Na ₂ SO ₄ Mixture	0.1850	0.1919	32	33	32
Least Significant Difference at 5% Level					11.4
at 1% Level					17.4

Considering possible explanations for the differences between salts, we see that sulphates are more toxic than chlorides, in combination with sodium and magnesium. This might be explained on the basis of either an anionic or a cationic effect. If the first were true, then the reason for the difference would be some toxic factor of the sulphate ion. However, comparing the ion concentration at isosmotic concentrations of sodium and magnesium sulphates, it can be seen that there is more than twice the sulphate present in the latter, and yet toxicities are approximately equal. If, on the other hand, the effect were cationic, we can compare the sodium ion concentrations in sodium sulphate and sodium chloride where there is almost twice the concentration of sodium in the former. Sodium sulphate is correspondingly considerably more toxic than sodium chloride. Again comparing the magnesium concentrations in magnesium sulphate and magnesium chloride, the magnesium in the former at isosmotic pressures is double that of the latter. The magnesium sulphate is correspondingly more toxic than the magnesium chloride. There appears to be some discrepancy in this reasoning however, for in comparing sodium chloride and magnesium chloride, the magnesium salt is more toxic, but comparing the sulphates, there is not much difference between them. However, this latter effect may be due to the fact that a large portion of the magnesium ions in the magnesium sulphate are associated.

Discussion under the section on calcium amelioration has already indicated negative results were obtained in an experiment designed to show that calcium might minimize the difference between the sulphate and chloride of sodium. Failure was also experienced as a result of fermentation, in an experiment in which it was attempted to balance the sodium content by the use of sucrose. However, on the other hand, the hypothesis was not disproven, and general data appear to uphold it.

COMPARISON OF THE TOLERANCE OF SPECIES TO A MIXTURE OF SALTS

As salinity under natural conditions represents a mixture of salts, the most appropriate means of testing a large number of species might be to use a mixture of salts in proportions similar to those of a representative saline soil of the area for which the species are to be tested. The solution chosen was a mixture of approximately equimoles of sodium and magnesium sulphates, there being also some sodium chloride present from the base nutrient solution. The three species, Ladak alfalfa, Alta fescue and tall wheatgrass were tested. Unfortunately it was impossible to get suitable seed of reed canarygrass in time for the experiment. The results of the experiment are recorded in Table X and graphically presented in Figure III. The average of the base and the first three concentrations were taken as the check for each species, the check germination percentage for Ladak alfalfa being 75 percent, of the Alta fescue 81 percent and of tall wheatgrass 85 percent. In order to obtain a basis of comparison between species, without altering too much the original data, all species were adjusted to the basis of an 80 percent check. Statistical analysis showed that there is a high significance between the interaction of species x concentration, between species and between concentrations. The osmotic pressures causing reduction of the different species to 50 percent of check germination are summarized as follows: Ladak alfalfa - 9.8 atmospheres, Alta fescue - 14.3 atmospheres, and tall wheatgrass - 16.7 atmospheres. It will be noticed in Table X that the weights of alfalfa seedlings are quite high, compared to Alta fescue. The grass seedlings were cut off above the seed, whereas the alfalfa seedlings were completely harvested, including the roots. The discrepancy thus introduced makes comparison invalid.

TABLE X. The Germination Percentage and Seedling Weight of Three Forage Species as Affected by Increasing Concentrations of a Mixture of Sulphates of Magnesium and Sodium with Base Nutrient Solution, in Covered, Sub-irrigated Sand Cultures.

Osmotic Pressure of Solution at 21°C as Determined by Freezing Point Depression	Ladak Alfalfa		Alta Fescue		Tall Wheatgrass	
	Percent Germ.	Average Weight per Seedling Milligrams	Percent Germ.	Average Weight per Seedling Milligrams	Percent Germ.	Average Weight per Seedling Milligrams
1.00	77.0	1.95	79.3	0.78	76.7	2.06
1.65	84.6	1.58	80.6	0.75	81.5	1.99
3.40	78.6	1.82	80.3	0.83	81.5	1.94
5.01	69.6	1.89	75.9	0.66	78.2	1.83
6.77	69.6	1.76	79.3	0.58	76.2	1.84
8.43	60.3	1.82	75.1	0.56	77.9	1.65
10.15	33.0	2.18	72.1	0.49	70.8	1.51
11.84	15.0	1.76	58.5	0.38	67.4	1.22
13.53	4.2	2.55	46.3	0.34	65.2	1.02
15.58			24.2	0.31	51.8	0.80
17.00			4.2	0.17	37.0	0.62
19.15					14.4	0.51
20.80					2.5	1.00
Average of Species	37.4		52.0		60.1	

Least Significant Difference Applicable to:

Species Average at 5% Level
at 1% Level

8.63% Germination
10.60% Germination

Species x Concentration (in body of Table)
at 5% Level
at 1% Level

12.24% Germination
16.20% Germination

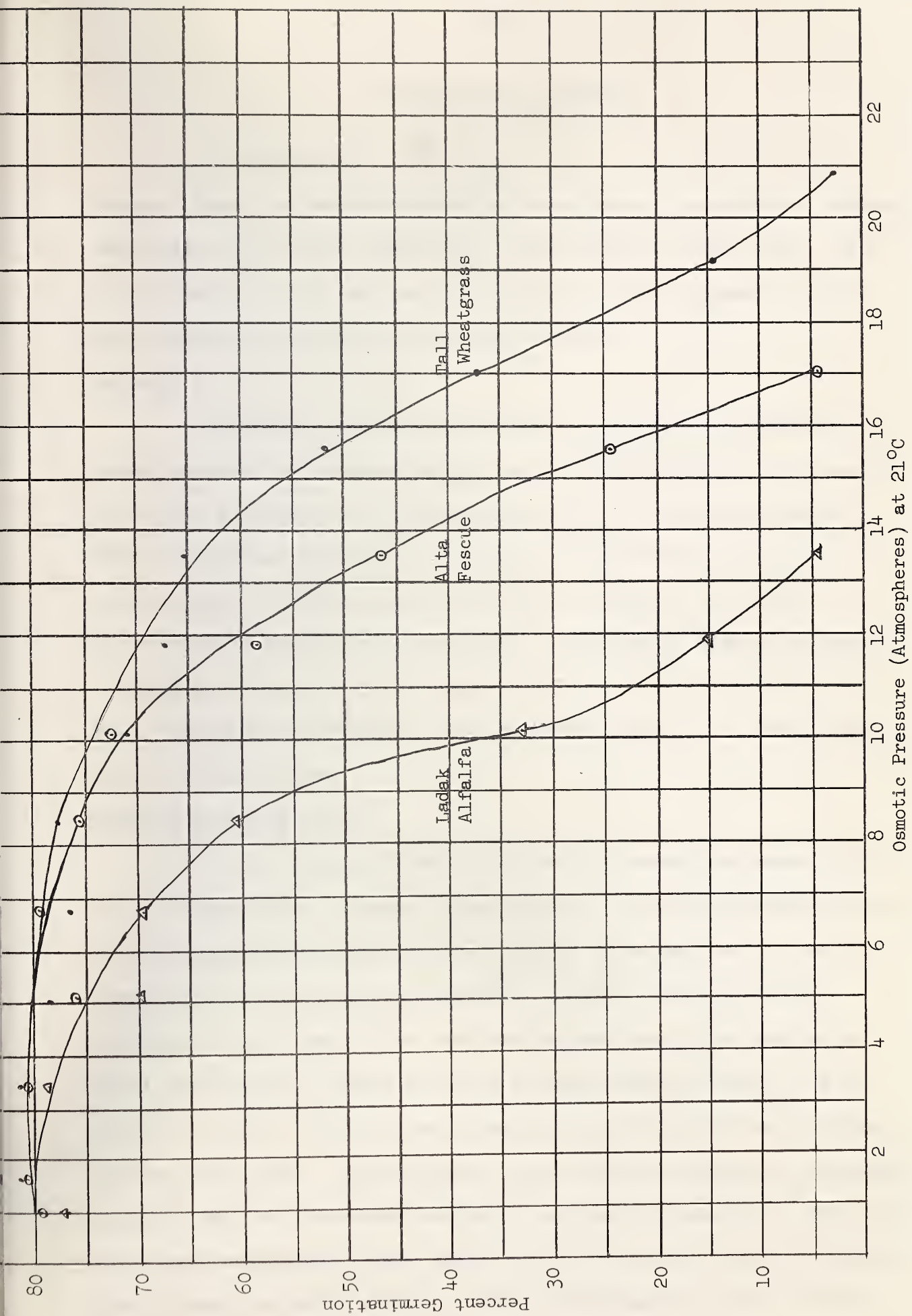


FIGURE III. The Germination Percentage of Ladak Alfalfa (*Medicago media*), Alta Fescue (*Festuca arundinacea*) and Tall Wheatgrass (*Agropyron elongatum*) as Affected by Increasing Osmotic Pressures of a Mixture of the Sulphates of Magnesium and Sodium Plus Base Nutrient Solution.

INTRODUCTION NURSERIES

Recommendations to the farmer cannot be given without field trials. Also, the research worker, in his efforts to evaluate all factors manifested in the field, must rely to some extent on field trials. Some field trials are reported here, with which an attempt is made to relate data obtained in controlled laboratory studies.

METHODS

Two general methods can be used to evaluate the usefulness of crops on naturally occurring saline areas: (1) the sowing of long narrow plots into a gradient of increasing salinity, the crops being planted side by side, and evaluated on the basis of the distance that growth survives into the area, and (2) the sowing of crops to be compared in plots suitable for obtaining yield data, on an area of uniform salinity, comparisons being made on the basis of yield, ecological stability and other factors of desirability. Both the above methods have been applied in the following work.

STAND ESTABLISHMENT DATA

In the spring of 1954 an introduction nursery was seeded into a saline seepage area occurring in the middle of a reed canarygrass seeding at the Canada Experimental Farm, Lethbridge. Plots were each three rows wide, at seven inch spacing between rows, and were sixty feet long, extending from an area of good reed canarygrass stand to an area of no stand, the boundary between stand and no stand occurring about half way along the plots. Two replicates were placed side by side, the following species being used: tall wheatgrass, Primar slender wheatgrass, Agropyron pungens, Amur and commercial strains of intermediate wheatgrass, Goar and Alta varieties of tall fescue, Russian wild rye, reed canarygrass, Nuttall alkali grass, and Ladak alfalfa. On May 25 and again on June 4, during

the period of germination, soil samples were taken from the surface inch, being made up of composite samples from the following locations: location (1) extended along the least saline end of the plots, where a good stand of reed canarygrass occurred, location (2) extended in a straight line across the middle of the test, where the boundary between growth and no growth occurred, and location (3) extended along the most saline end of the plots. Moisture percentages were determined on the May 25 samples. Chemical analyses and conductivities were obtained on the saturation (5:3) extracts, procedures used being those outlined by the U.S. Regional Salinity Staff, Riverside, California, in their manual "Diagnosis and Improvement of Saline and Alkali Soils". Results are shown in Table XI.

Using a pressure plate apparatus at a pressure of 0.63 ± 0.06 atmospheres, the moisture percentage was reduced to 15.5 percent. By taking the moisture percentage of 18.8 found in the field, it was possible to estimate a soil moisture tension of 0.5 atmospheres. The osmotic pressure of the 5:3 extract was determined graphically by using conductivity data appearing in Table XI. The factor 3.45 was used to convert the values to a moisture content of 18.8 percent at 21°C , and by adding to each of these the moisture tension of 0.5 atmospheres, the final values of total moisture stress obtained were as follows: location (1) - 9.82 atmospheres, location (2) - 16.0 atmospheres, and location (3) - 20.0 atmospheres.

The plots were very weedy in the year of seeding and it was difficult to obtain good stand records. However, it was apparent that the best stands were obtained with tall wheatgrass which produced excellent stands in all plots, while Agropyron pungens, which produced the next best stand was nowhere inhibited but appeared somewhat thinner. Primar slender wheatgrass produced fair stands over most of the length of the plot in

TABLE XI. The Chemical Analyses and Conductivities of Saturation Extracts, the Conductivities of Soil Pastes, and the pH Determinations of Surface Soil Samples taken from Three Different Locations in a Plant Introduction Nursery at Lethbridge, Alberta, 1954.

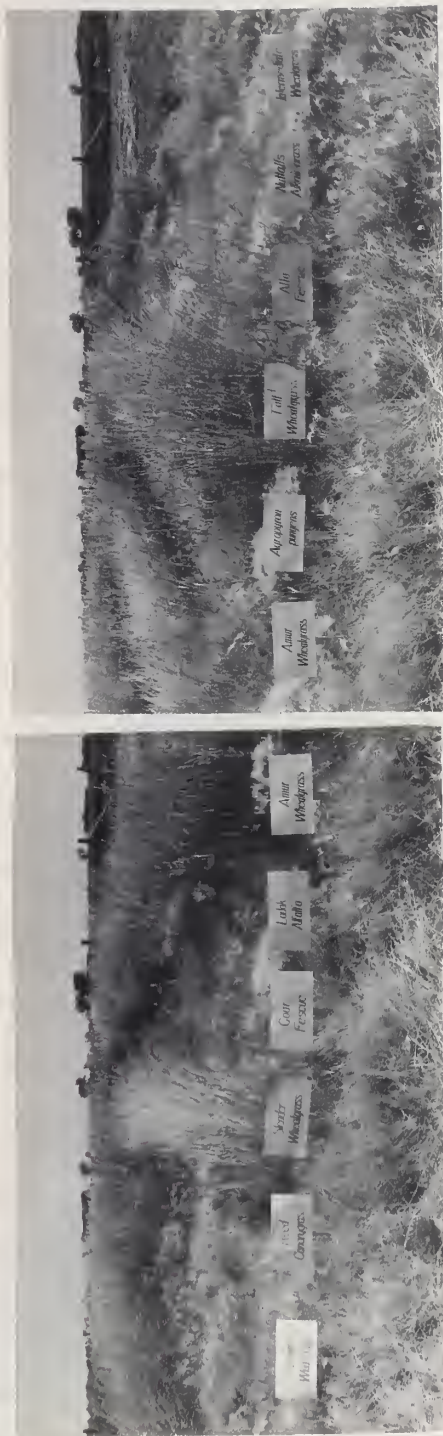
Location	Date	pH	Conductivity		Soluble Salts, Milliequivalents per liter					
			Millimhos per Centimeter	Saturation Extract	Na	Ca	Mg	SO ₄	Cl	HCO ₃
1	May 25/54	7.67	5.22	6.74	64.8	27.8	60.2	139.8	1.0	12.0
2	May 25/54	7.93	5.22	12.00	49.0	32.1	144.6	214.2	2.1	9.4
3	May 25/54	8.12	5.22	14.87	16.4	35.4	232.0	272.5	0.9	10.4
1	June 4/54	7.70	5.22	7.27	14.1	28.5	67.5	101.9	0.1	8.1
2	June 4/54	7.93	5.22	10.96	22.3	33.8	127.5	173.5	1.0	9.1
3	June 4/54	8.17	8.71	13.72	44.6	30.3	200.1	267.1	0.4	7.5

replicate two but did not do so well in replicate one. In this test Alta fescue was noticeably poorer in stand than Goar fescue and was only slightly better than reed canarygrass, the term "sporadic plants" being descriptive. The two strains of intermediate wheatgrass and also Russian wild rye made very poor stands throughout. Alfalfa stands stopped abruptly at about the half way (16.0 atmospheres) level. It was almost impossible to discern any stands of Nuttall alkali grass because of an infestation of the same species from a native stand already present.

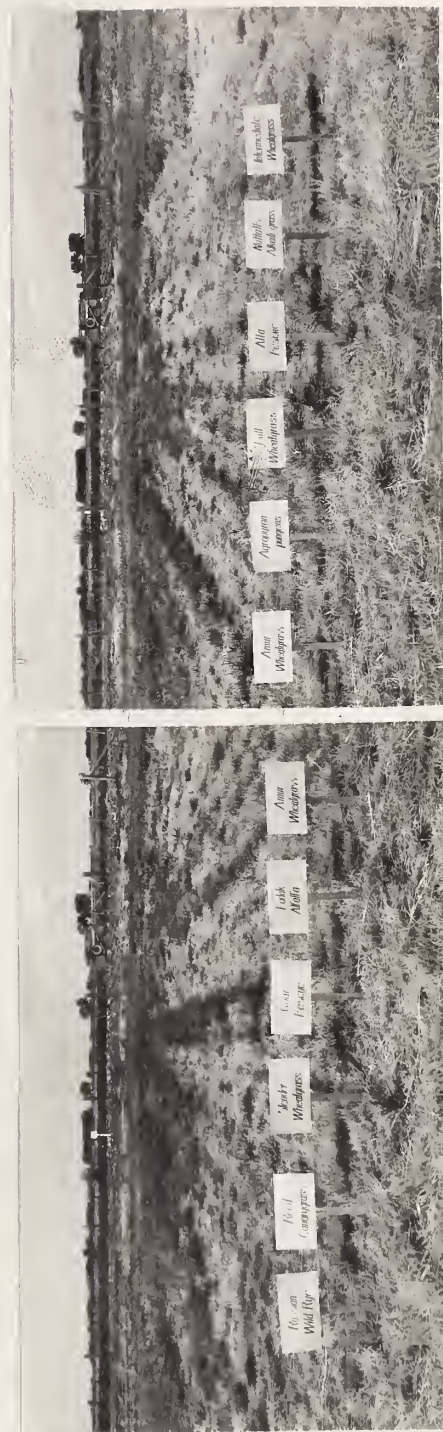
An excellent idea of the stands was obtained in the following year and photographs in Plate II show the appearance of the nursery before cutting and after recovery from cut. The excellence of the growth of tall wheatgrass can be seen in the picture before cutting. The possible value of Goar fescue, a variety of tall fescue, is indicated in the second picture in which its recovery is shown to be by far the best. However, it will be noted from the picture that it did not produce a solid stand to the end of the row, the description "sporadic stand" being used to describe stands of this nature.

In the spring of 1955, a fairly uniform saline area was obtained at Vauxhall. The area was seeded down in the previous year to a standard pasture mixture and there was a complete failure of stand establishment because of soil salinity. The only vegetation at the time of acquisition consisted of scattered plants of wild barley. A block of this land was ploughed and worked into a very firm seed bed. A four replicated test consisting of eleven forage species in plots seeded side by side, three rows wide at seven inch spacing, and one hundred and eighty feet long was seeded. At time of germination composite soil samples were taken from the surface inch, one sample being taken from five locations in each replicate. The locations were spaced evenly along the length of the replicate, number one being at the beginning of the row, number two at

PLATE II.



(a) Introduction nursery on a saline seepage area at Lethbridge, 1955.



(b) Same nursery as above, after cutting and recovery from cut.

the forty-five foot location, number three at the ninety foot location, number four at the one hundred and thirty-five foot location and number five at the one hundred and eighty foot location.

Moisture determinations were made on the soil samples at the time of taking. The following winter, saturation extracts were obtained and freezing point depression and conductivities were made on these extracts. Also, in order to estimate moisture stress the samples were subjected to a pressure of 0.63 atmospheres and moisture determinations were made. Using these data, estimations of the osmotic pressure occurring at each location at about the time of seed germination were made and recorded in Table XII..

The stands obtained were evaluated in the fall after seeding, and a summary of the data of those species establishing stand are recorded in Table XIII. The stands between each of the samples are presented and the estimation of osmotic pressure and conductivity are averages of the two samples between which the stand estimation lies. It is evident from the data that the piece of land used was very uniform in its salinity, which was of a moderate level, and most tolerant species established good stands except for a few in which other factors were apparently active. The only species which can be definitely stated to be almost entirely inhibited because of salinity was orchard grass. Nuttall alkali grass also produced no stands but the factors affecting the establishment of this species, which is a native halophyte, are not known. The species Amur intermediate wheatgrass, Primar slender wheatgrass, Agropyron pungens and white blossom sweet clover gave very spotty stands, mostly being classified as "sporadic plants". The reason why these species failed to become well established is not known and indeed the stands might fill out in the second year of growth, which has not commenced at the time of writing. Of the remaining species, tall wheatgrass produced good stands throughout

TABLE XII. The Conductivity of the Saturation Extract and the Determination of Total Soil Moisture Stress in Atmospheres by Summation of Osmotic Pressure of Soil Solution as Determined by Freezing Point Depression and an Estimated 0.17 Atmospheres Soil Moisture Tension, Determined on Surface Samples from an Introduction Nursery at Vauxhall, Alberta, 1955.

Plot #	Osmotic Pressure of Saturation Extract (33.3% Water) at 21°C by Freezing Point Depression	Percent Water in Soil	Estimated Osmotic Pressure of Soil Solution at Time of Sampling	Total Soil Moisture Stress (add 0.17 Atmospheres)	Average Stress Between Sample Locations	Conductivity of Saturation Extract (corrected to 25°C)	Average Conductivity Between Sample Locations
Rep. I							
1	3.17	16.1	7.15	7.32	7.77	8.8	8.3
2	3.17	14.5	8.05	8.22	7.57	7.8	7.6
3	2.86	16.2	6.75	6.92	7.55	7.4	7.7
4	3.42	16.3	8.02	8.19	7.50	8.0	7.8
5	2.59	14.9	6.64	6.81		7.5	
Rep. II							
1	3.36	16.2	7.92	8.09	8.15	8.6	8.6
2	3.36	16.0	8.04	8.21	7.32	8.6	8.3
3	2.78	17.0	6.25	6.42	6.86	8.0	8.0
4	2.80	15.0	7.14	7.31	6.98	8.1	8.3
5	2.84	16.8	6.47	6.64		8.5	
Rep. III							
1	2.95	15.3	7.38	7.55	7.97	7.1	8.2
2	3.48	16.2	8.22	8.39	7.99	9.1	8.8
3	3.23	16.6	7.42	7.59	7.87	8.8	8.8
4	3.23	15.5	7.98	8.15	8.30	8.8	9.4
5	3.42	15.8	8.27	8.44		10.1	
Rep. IV							
1	2.46	16.3	5.75	5.92	7.13	7.7	8.4
2	3.78	17.7	8.17	8.34	7.52	9.0	8.4
3	3.02	17.7	6.53	6.70	7.82	7.8	8.8
4	3.90	17.0	8.78	8.95	8.76	9.9	9.6
5	3.38	15.4	8.39	8.56		9.2	

TABLE XIII. The Effect of Soil Salinity, Previously Shown in Table XII, on the Percentage Stand Establishment of Various Forage Crops in an Introduction Nursery at Vauxhall, Alberta, 1955.

Plot Number	Osmotic Pressure at 21°C	Conductivity at 25°C	Tall		Ladak		K 31		Alta		Reed Canary Grass		Average	
			Wheatgrass		Alfalfa		Tall Fescue		Tall Fescue		Grass		All Species	
			Good	to Fair	Good	to Fair	Good	to Fair	Good	to Fair	Good	to Fair	Good	to Fair
			Stand	Stand	Stand	Stand	Stand	Stand	Stand	Stand	Stand	Stand	Stand	Stand
			Total	Total	Total	Total	Total	Total	Total	Total	Total	Total	Total	Total
Rep. I														
1	7.77	8.3	88	100	88	88	38	81	44	69	88	88	69	85
2	7.57	7.6	75	75	56	85	43	82	0	13	100	100	55	71
3	7.55	7.7	100	100	0	88	31	62	0	6	0	100	26	71
4	7.50	7.8	88	100	50	100	69	81	0	6	0	50	44	67
Average	7.60	7.8	90	94	48	90	46	76	11	24	47	84	48	74
Rep. II														
1	8.15	8.6	100	100	100	100	88	88	62	88	31	100	76	95
2	7.32	8.3	100	100	100	100	88	94	69	100	50	100	81	99
3	6.86	8.0	100	100	100	100	12	62	25	100	0	100	47	92
4	6.98	8.3	100	100	38	100	56	81	12	100	0	81	41	92
Average	7.33	8.3	100	100	84	100	61	81	42	97	20	95	61	94
Rep. III														
1	7.97	8.2	100	100	75	100	75	100	88	100	0	100	68	100
2	7.99	8.8	100	100	18	100	62	100	100	100	0	81	56	96
3	7.87	8.8	75	100	56	100	75	100	50	100	0	100	51	100
4	8.30	9.4	43	100	0	0	6	75	38	100	0	100	17	75
Average	8.03	8.8	80	100	37	75	54	94	69	100	0	95	48	93
Rep. IV														
1	7.13	8.4	38	81	81	100	75	100	100	100	19	100	63	96
2	7.52	8.4	100	100	12	100	75	100	19	100	25	100	46	100
3	7.82	8.8	100	100	12	100	38	100	38	100	0	75	38	95
4	8.76	9.6	100	100	25	100	0	88	88	100	0	44	43	66
Average	7.81	8.8	84	95	32	100	47	97	61	100	11	80	48	89
Grand Average		8.4	88	97	51	91	52	87	46	80	20	89		

whereas Ladak alfalfa, K31 fescue and Alta fescue produced good to fair stands over about 50 percent of the area in which they were seeded, while reed canarygrass produced good to fair stands on 20 percent of the area seeded. The fact that these evaluations have been set on the stands obtained in the year of seeding does not necessarily mean that the final result is indicated. It is to be expected that the grass species will fill in their stands to a greater extent than the legumes, and also of the grass species those with creeping roots such as reed canarygrass might be more successful in this respect.

YIELD DATA

In 1953 a small experiment of four replicates was seeded in plots thirty feet long and thirty inches wide, with six inch row spacing. Two replicates occurred in a somewhat more saline portion than the other two, and conductivity readings taken on the saturation extract of three surface samples taken in the year of seeding showed an average 13.5 millimhos per centimeter. The species seeded, and their yields in the years 1954 and 1955 are summarized in Table XIV. Excellent stands were obtained for tall wheatgrass, Russian wild rye, Agropyron pungens and Alta fescue in all replicates, while reed canarygrass produced excellent stands on the less saline replicates, but patchy stands on the more saline ones. Amur strain of intermediate wheatgrass and Nuttall alkali grass produced generally thin or patchy stands. All species did much better in the less saline replicates, but tall wheatgrass still gave excellent yields, even in the most saline portions. Analysis of variance showed that tall wheatgrass outyielded all other species by far, and gave an average yield of over 4.5 tons per acre. The average for all other species was between 1 and 1.8 tons per acre. The extremely high yield of tall wheatgrass may be partly due to border effect, as the plots were narrow, and received little competition from neighboring plots.

TABLE XIV. Tons of Forage, Dry Matter per Acre, Harvested from Plots Replicated Four Times on a Saline Seepage Area at the Canada Experimental Farm at Lethbridge, Alberta.

Species	1954	1955	2 Year Average
Tall Wheatgrass (<u>Agropyron elongatum</u>)	3.82	5.55	4.68
Intermediate Wheatgrass, Amur (<u>Agropyron intermedium</u>)	1.44	1.62	1.53
<u>Agropyron pungens</u>	1.58	1.40	1.49
Russian Wild Rye (<u>Elymus junceus</u>)	1.05	1.03	1.04
Tall Fescue (<u>Festuca arundinacea</u>)	1.26	2.30	1.78
Reed Canarygrass (<u>Phalaris arundinacea</u>)	1.15	2.32	1.74
Nuttall Alkali Grass (<u>Puccinella aeroides</u>)	0.91	2.11	1.51
Least Significant Difference at 5% Level	1.32	0.98	1.03
Least Significant Difference at 1% Level	1.81	1.34	1.37

GENERAL DISCUSSION OF RESULTS

Data have been obtained on the germination of three species, tall wheatgrass, tall fescue and alfalfa in a mixture of increasing osmotic pressures of sodium sulphate and magnesium sulphate, the respective 50 percent levels of germination being caused by concentrations of 16.6, 14.3 and 9.8 atmospheres respectively. Data have also been obtained from field trials, in which the osmotic pressures of the soil solution have been estimated at the time of germination by use of the saturation extract. In the 1954 test reported, alfalfa was inhibited by a moisture stress of 16 atmospheres pressure, while Alta fescue and reed canarygrass produced a considerable stand of sporadic plants in the region between 16 and 20 atmospheres, Coar fescue, slender wheatgrass and Agropyron pungens produced fair to sporadic stands, while tall wheatgrass produced an excellent stand in this same gradient.

The results of the following year did not give such excellent agreement with laboratory results, though differences can be explained to some extent. In the first place the salt concentrations were considerably lower than those of the previous test, the calculated osmotic pressure of the solution being about 8 ± 0.5 atmospheres. Tall wheatgrass produced generally good stands throughout the area, while alfalfa and two varieties of tall fescue were somewhat reduced in stand, only 50 percent being classed as good to fair. However, it is to be expected that some of the stands will fill out in the following year. Also, the following sequence of events is believed to have been instrumental in producing observed results. After seeding, excellent moisture conditions existed, causing good germination of the alfalfa, which is relatively quick to germinate. Owing to a gradual drying of the soil, and increasing of moisture stresses, by the time some of the grasses such as tall fescue were ready to germinate, the moisture stress had increased to the point of being inhibitory.

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APPENDIX

The manipulation of the preceding work entailed the preparation of solutions of various combinations of salts at certain concentrations of predetermined osmotic pressure. Though the physical basis for such calculations has long been laid, and indeed facilitating graphs of various types have no doubt been prepared in the past, such graphs are not widely publicized to the knowledge of the author, and considerable research was necessitated before suitable curves were obtained. For that reason it was felt desirable to present the curves and method of calculation, the former appearing in the chart folded inside the back cover.

Osmotic pressure given by the molal concentrations of various salts can be calculated by the gas equation modification:

$$\Pi = m i R T$$

Where m is the molality
 i is van't Hoff's factor
 R is the gas constant (0.082 for liter atm.)
 T is the absolute temperature

Such an equation requires the acquisition of a value for i , which up to the present is most readily available from the freezing point depression data obtainable from International Critical Tables, being determined by the expression $i = \Delta T_f / 1.86M$, where ΔT_f is the freezing point depression, observed at the molal concentration M . However, it will be noted that by substituting the value $\Delta T_f / 1.86M$ in the gas equation, the values M cancel, indicating that the osmotic pressure can be calculated directly from the freezing point depression, without a knowledge of concentration, this being in its most simple form $\Pi = 12.06 \Delta T_f$, which is equivalent to the gas formula. Using the gas formula however it was necessary to determine i from a graph in which the unknown concentration must first be estimated. Utilizing the latter formula, however, and plotting

osmotic pressure as determined by the freezing point depression, it is possible to eliminate the estimate of concentration. The only calculation necessary is that of reduction of the temperature at which the solution is to be used to 273.16°K (0°C) for which temperature the graph is constructed. The concentration can be then determined graphically from there, without further calculation.

In drawing up the graphs certain corrections were found to be applicable: Lewis (1908) showed that a more correct formula for the calculation of osmotic pressure from freezing point depression data is $\Pi = 12.06 \Delta T_f - 0.021 \Delta T_f^2$. Harris and Gortner (1914) considered this correction of importance and derived a table for converting freezing point data to osmotic pressure. They also mention another factor, the crystallization of pure solvent out of solution upon freezing, making a more concentrated solution and giving an excessively low value for ΔT_f . They suggest a correction formula $\Delta T_f = \Delta T_f - 0.0125 u \Delta T_f$, where u is the degree of undercooling. Where a certain freezing point is anticipated, freezing can be initiated by addition of dry crystals of ice when the appropriate temperature has been reached, thus eliminating necessity of applying the above correction. Data appearing in International Critical Tables have not been obtained by the supercooling method, so this correction is not required there. In calculating the osmotic pressure at zero degrees centigrade (273.16°K) the freezing point actually observed is somewhat lower, and a correction $\frac{273.16}{273.16 - \Delta T_f} \times \Delta T_f$ is applicable. The application of these corrections to freezing point data found in International Critical Tables are summarized in Table I(A).

In making up solutions on the basis of molal concentrations, it is necessary to weigh separately the salt for each concentration and add, preferably by weight, the appropriate quantity of water. Though for very accurate work, such a procedure is no doubt best, for much of the data

TABLE IA. The Calculation of Osmotic Pressures from Freezing Point Data from International Critical Tables.

	M O L A L C O N C E N T R A T I O N S						
	0.01	0.02	0.05	0.10	0.20	0.50	1.0
CaCl ₂							
Freezing Point Depression	0.05112		0.2443	0.4832	0.956	2.490	
O.P. Δ - 0.021 Δ ²	0.6165		2.945	5.812	11.510	29.900	
Osmotic Pressure at 0°C	0.6165		2.945	5.818	11.551	30.174	
Osmotic Pressure Δ - 12.06 Δ	0.6165		2.946	5.827	11.529	30.029	
MgCl ₂							
Freezing Point Depression	0.05144		0.2487	0.4938	0.9954	2.690	
O.P. Δ - 0.021 Δ ²	0.6204		2.998	5.9501	11.984	32.299	
Osmotic Pressure at 0°C	0.6205		3.001	5.961	12.028	32.621	
Osmotic Pressure Δ - 12.06 Δ	0.6204		2.999	5.955	12.004	32.441	
MgSO ₄							
Freezing Point Depression	0.0285		0.1210	0.2252	0.4180	2.02	
O.P. Δ - 0.021 Δ ²	0.3437		1.459	2.715	5.037	24.276	
Osmotic Pressure at 0°C	0.3437		1.460	2.717	5.045	24.456	
Osmotic Pressure Δ - 12.06 Δ	0.3437		1.459	2.716	5.041	24.361	
NaCl							
Freezing Point Depression	0.03604	0.07140		0.3478	0.6848	3.37	
O.P. Δ - 0.021 Δ ²	0.4346	0.8611		4.192	8.249	40.404	
Osmotic Pressure at 0°C	0.4346	0.8613		4.197	8.270	40.908	
Osmotic Pressure Δ - 12.06 Δ	0.4346	0.8611		4.194	8.259	40.642	
Na ₂ SO ₄							
Freezing Point Depression	0.0504	0.09748		0.4344	0.8114	0.25*	
O.P. Δ - 0.021 Δ ²	0.6078	1.175		5.236	9.772	0.9860	
Osmotic Pressure at 0°C	0.6078	1.176		5.244	9.801	11.875	
Osmotic Pressure Δ - 12.06 Δ	0.6078	1.176		5.239	9.786	11.918	
Ca(NO ₃) ₂							
Osmotic Pressure Δ - 12.06 Δ			0.235				
			2.83				
KH ₂ PO ₄							
Osmotic Pressure Δ - 12.06 Δ		0.0718	0.1835				
		0.865	2.215				

* Moles Concentration

involving plant growth the biological variation is far greater than these minor variations, and volumetric measurements are accurate enough. In order that volumetric work can be facilitated, density data appearing in International Critical Tables have been used to convert molal concentrations to molar, and the corresponding curves have been drawn on the same axes as the molal. The original data used and their conversions are recorded in Table II(A).

In the weighing of large amounts of water or salt (in hundreds of grams) the bouyant effect of air may have a considerable effect where high accuracy is required. To facilitate in vacuo readings, Table III(A) is included, which shows calculated corrections applied to molecular weights of the salts commonly used in high concentrations, and also for 1000 grams of water. The data were obtained from the Handbook of Physics and Chemistry (1954). These differences will affect the fourth figure of molar concentrations. As the graphical readings can be made to the fourth figure, this factor should be considered in accurate work.

There are certain limitations to the use of the freezing point depression as a criterion of osmotic pressure which might be mentioned. Sodium sulphate is a very common cause of salinity in soils, and it will be noticed from the graph that its curve does not extend as a solid line beyond 0.25 moles. The reason for this is that at the freezing point, pure solutions of sodium sulphate in excess of 0.25 moles will precipitate out. However at temperatures where plant growth occurs, much more sodium sulphate will dissolve, concentrations of 1 mole being easily prepared. The curves derived from the freezing point have been extrapolated (in dots) a short distance to the 16 atmosphere level, for the purpose of making up solutions, though in actual fact the curves do not exist at that point. It has been found that in the presence of base nutrient solutions, the

TABLE IIA. Conversion of Molal Concentrations to Molar Using Density Data from International Critical Tables.

% Sol.	Grams Salt per 1,000 Grams H ₂ O	NaCl (58.454)			Na ₂ SO ₄ (142.06)			MgSO ₄ (120.39)		
		Molality	Grams Salt Per Liter	Molarity	Molality	Grams Salt Per Liter	Molarity	Molality	Grams Salt Per Liter	Molarity
2	20.408	0.3491	20.25	0.3464	0.1436	20.33	0.1431	0.1695	20.37	0.1692
4	41.666	0.7128	41.07	0.7026	0.2933	41.39	0.2914	0.3461	41.57	0.3453
6	63.829	1.0920	62.48	1.0689	0.4493	63.21	0.4450	0.5302	63.61	0.5284
8	86.956							0.7223	86.53	0.7187
10	111.111							0.9229	110.3	0.9162
% Sol.	Grams Salt per 1,000 Grams H ₂ O	MgCl ₂ (95.23)			CaCl ₂ (110.99)					
		Molality	Grams Salt Per Liter	Molarity	Molality	Grams Salt Per Liter	Molarity			
2	20.408	0.2143	20.29	0.2131	0.1839	20.30	0.1829			
4	41.666	0.4375	41.24	0.4330	0.3754	41.26	0.3717			
6	63.829	0.6703	62.87	0.6602	0.5751	62.92	0.5669			

TABLE IIIA. In Vacuo Weighings of Molecular Weights of Various Salts and of 1000 Grams of Water

Salt	Density	K	Actual Molecular Weight	Read on Balance Pt Ir Weights
Na_2SO_4	2.698	0.39	142.06	142.00
$\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$	1.464	0.77	322.22	321.97
NaCl	2.165	0.51	58.45	58.42
MgSO_4	2.66	0.40	120.39	120.34
$\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$	1.636	0.68	246.50	246.32
$\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$	2.24	0.49	147.03	146.96
$\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$	1.56	0.71	203.33	203.18
H_2O	1.00	1.14	1000 grams	998.86

solubility at the freezing point is somewhat increased, and the extrapolation has been found valid enough.

Although the freezing point depression is an exact criterion of the osmotic pressure at the freezing temperature, there is a possibility of a change in the hydration of some of the ions at higher temperatures, which would in turn affect the osmotic pressure. Evidence obtained by Morse (1914) indicates excellent agreement between the osmotic pressure as derived from the freezing point and that obtained by the direct method, using solutions of sugar and lithium chloride. His work also substantiates the direct relation between absolute temperature and osmotic pressure using sugar solutions. However the difficulties encountered in making direct measurements on the various salts due to their reaction with the membranes, and the difficulty of obtaining membranes completely impermeable has limited very much the work done on ordinary salts.

The osmotic pressures of solutions may also be derived from vapor pressure lowering, using the relation $\Pi = \frac{RT}{v} \ln \frac{P^0}{P}$,

where R is the gas constant (liter atmospheres)
 v is the volume of 1 mole of solvent
 T is the absolute temperature
 P^0 is the vapor pressure of pure solvent (liters)
 P is the vapor pressure of solution
 Π is the osmotic pressure of the solution (atm.)

Vapor pressure data at the boiling temperature of various solutions starting at concentration of 0.5 molal are available in the Handbook of Physics and Chemistry. Tabulated below are comparisons of osmotic pressures calculated by both methods at that concentration.

Salt (0.5 moles)	CaCl ₂	MgCl ₂	NaCl	Na ₂ SO ₄	MgSO ₄
Osmotic Pressure by Freezing Point	30.10	32.60	20.50	---	11.85
Osmotic Pressure by Vapor Pressure	28.17	27.80	20.22	20.72	9.05

The osmotic pressures were calculated for the boiling temperature, and then reduced to 0°C. The fact that the salts giving the most divergent results from the two methods are those of calcium and magnesium, which are highly hydrated, and that in every instance the vapor pressure method gives the lower value, would indicate a possible cause for the divergence to be a loss in hydration at the higher temperature. However, the temperatures at which the experiments are conducted are much closer to the freezing point than the boiling point lending strength to the belief that the freezing point data are the more correct to use. Vapor pressure measurements could be made at the temperature used, but it would be very difficult to get accurate results, as readings are very small at the lower temperature.

PROCEDURE FOR MAKING UP SALT SOLUTIONS

In work such as this, in which the toxic effects of various salts in the presence of a complete nutrient solution are to be determined, it is convenient to make up a base nutrient solution, and then to bring up the osmotic pressure to the desired level by addition of single salts or mixtures of salts. As hydrated salts are often used, the same amount of water is not always to be added, and it is important to supply the same amount of base nutrient to each culture. Therefore it is necessary to make up a more concentrated salt solution and to bring up the weight or volume as desired by addition of distilled water. Also when doing volumetric work, it is convenient to prepare 1 molar solutions of each salt, to pipette the required volume from a burette into a volumetric flask, then to add the required amount of concentrated base nutrient solutions, and finally to bring up to volume with distilled water. A concentration of three times the final, of base nutrient solution has been found suitable.

In making up the base nutrient solution it was found convenient to prepare a liter of FeCl_3 and tartaric acid in water, and also another liter containing the micro elements, one cubic centimeter of each being added per liter of final solution to the base nutrient solution. The macro nutrients can all be dissolved together, but it was found best not to add the K_2HPO_4 or basic part of the buffer till the final solutions had been made up, when the K_2HPO_4 could be added in solution, and used to titrate the final solution to the desired pH by means of a pH meter.

The following is an example of the quantities of salt and water required to make up a solution of a certain osmotic pressure. Suppose it is required to make up a solution of 16.00 atmospheres osmotic pressure, at 20°C using $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$. Converting to 0°C we have $\frac{273.16}{293.16} \times 16 = 14.91$ atmospheres. Reading from the graph this requires 0.618 moles on the molal basis. The water of hydration supplies $0.618 \times 7 \times 18.02 = 78.0$ grams of water. Then for 1 liter of solution 921.63 grams of water should be weighed in. The same value is obtained from the gas equation, where considerably more calculation is required, and the value for i must be obtained from a graph in any case. If the volumetric method were to be used, however, it would simply involve taking the molar reading from the graph, and bringing the solution up to the desired volume, care being taken that the temperature is at 20°C , at which temperature most volumetric equipment is calibrated.

PROCEDURE FOR FREEZING POINT DETERMINATIONS

As a number of difficulties were encountered in learning the technique for freezing point determinations, a summary of the methods and some error sources is desirable here. A one gallon crock with a lower drain was used as a bath, this being placed inside a two gallon

crook and packed with excelsior. A rubber tube was run from the drain to a sink to remove excess water as desired. Circulation of the bath was maintained by an electric stirrer operating in a covered shaft. Ice water was used as the coolant, a temperature of -6°C being maintained by addition of appropriate amounts of salt (estimated). The freezing chambers were made from test tubes 4 x 20 centimeters, fitted inside plastic centrifuge tubes 5 x 16 centimeters. A Heidenhain cryoscopic thermometer (mercury in pyrex) was used. A small mouthed thermos was used for holding the thermometer when not in use, and for checking the zero point, and a wide mouthed thermos was used for washing the thermometer in ice water.

Some difficulty was obtained in getting a consistent zero point on the thermometer. In determining the zero point from a mixture of chopped ice and distilled water in the small thermos, excessively low readings were obtained for an hour or so after making up the mixture, this being explainable on the basis that the ice from the refrigerator was at a temperature considerably below zero, causing a time lag in obtaining the equilibrium temperature. Also it was thought that the expansion and contraction lag in the pyrex of the thermometer might be a factor, so the evening before an experiment was anticipated the thermometer was placed in the thermos with ice water, and when being used it was always washed in ice water, the mercury not being allowed to enter very far into the terminal reservoir. After washing it was always dried well and quickly with a clean piece of Kleenex tissue, before placing in the next solution to be determined. The zero point was checked each day by both the ice water and supercooling methods.

The temperature of the bath was also found to be a factor in obtaining accurate results. An under cooling of $5^{\circ}\text{C} \pm 0.5$, caused no appreciable error. Excessive undercooling will cause an outward flow of heat from the freezing chamber fast enough to cause more ice to crystallize out resulting in a lower freezing point before the maximum temperature has been reached.

The method used in obtaining the actual freezing point reading (the approximate value being already known) was to super cool by approximately 0.3°C , and to initiate freezing by addition of an ice crystal from a spatula to the stirrer, which was immediately returned to the solution. The ice crystals and spatula were kept in a test tube in the freezing bath, so that they were both maintained in a dry condition, and there was no dilution of solution by addition of the crystal. Fairly vigorous stirring was used till the mercury almost reached the maximum point, when regular stirring was maintained between readings. Readings were taken every few seconds at about the maximum point till a definite dropping was observed. If there was a constant maximum, that was taken as the freezing point. Otherwise an average of the high readings was taken.

SPHERES

20

19

18

17

16

15

14

13

Mg Cl₂ MOLAR

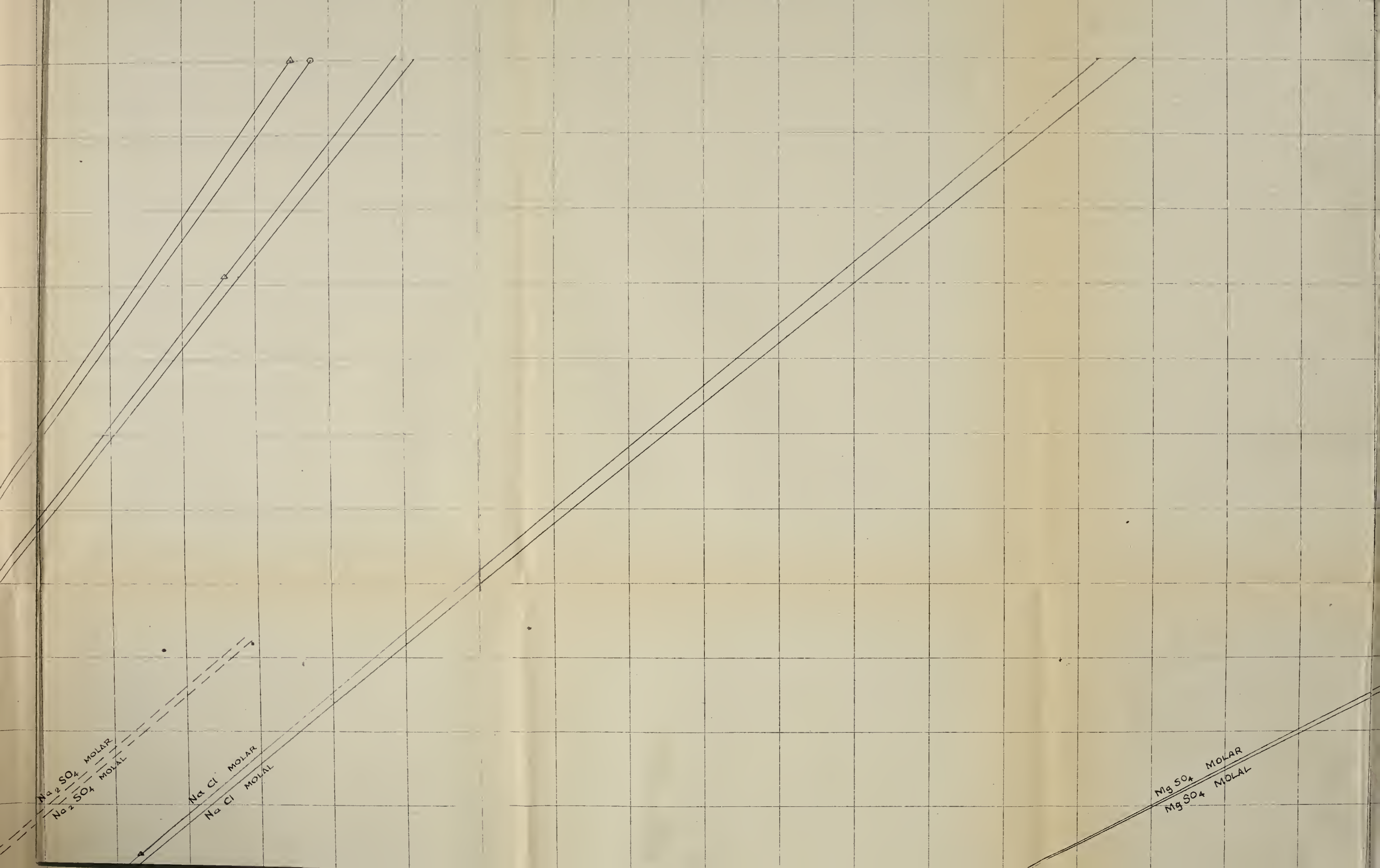
Mg Cl₂ MOLAL

Ca Cl₂ MOLAR

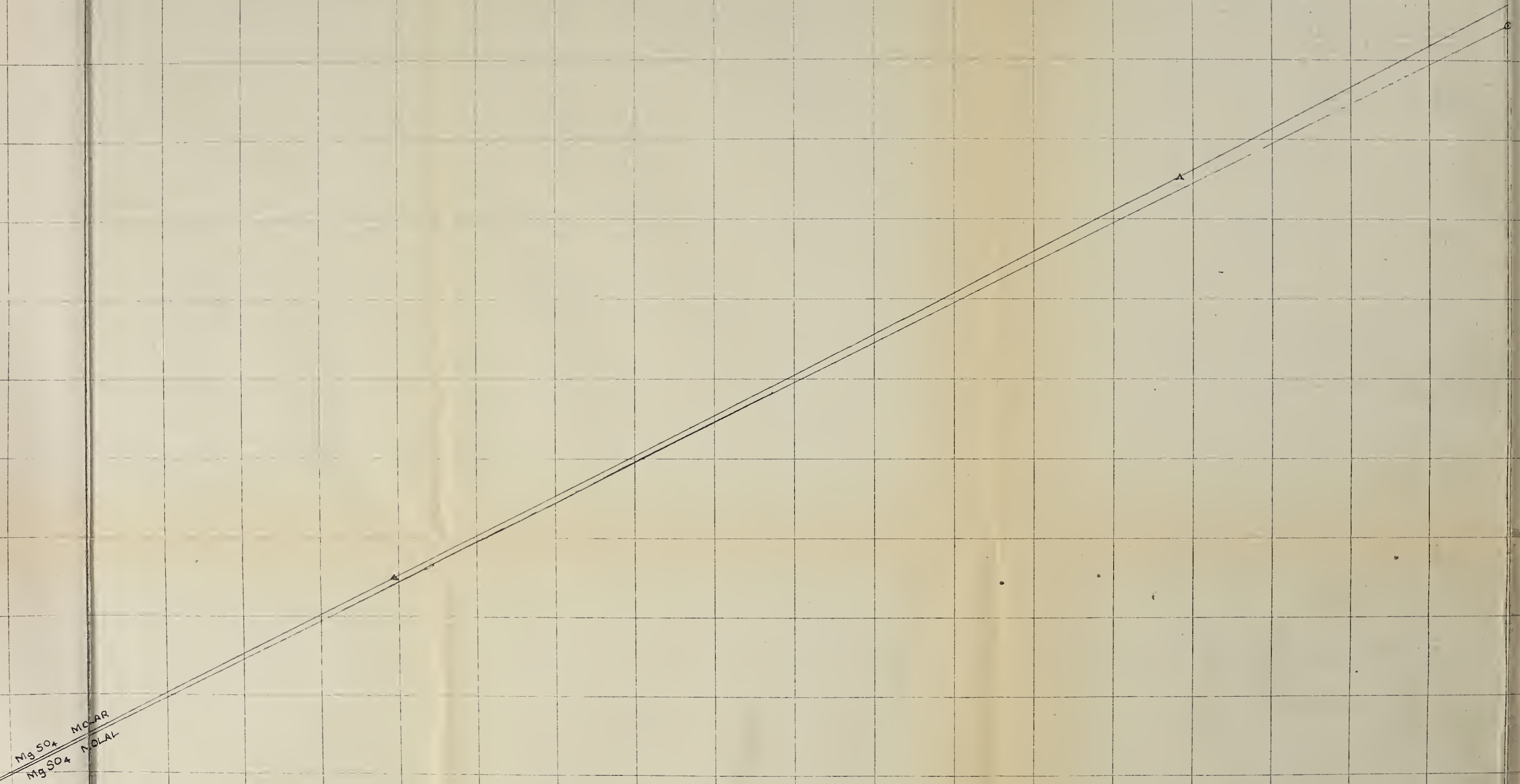
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Na₂ SO₄ MOLAR

Na₂ SO₄ MOLAL



MgSO₄ MOLAR
MgSO₄ MOLAL



ATMOSP

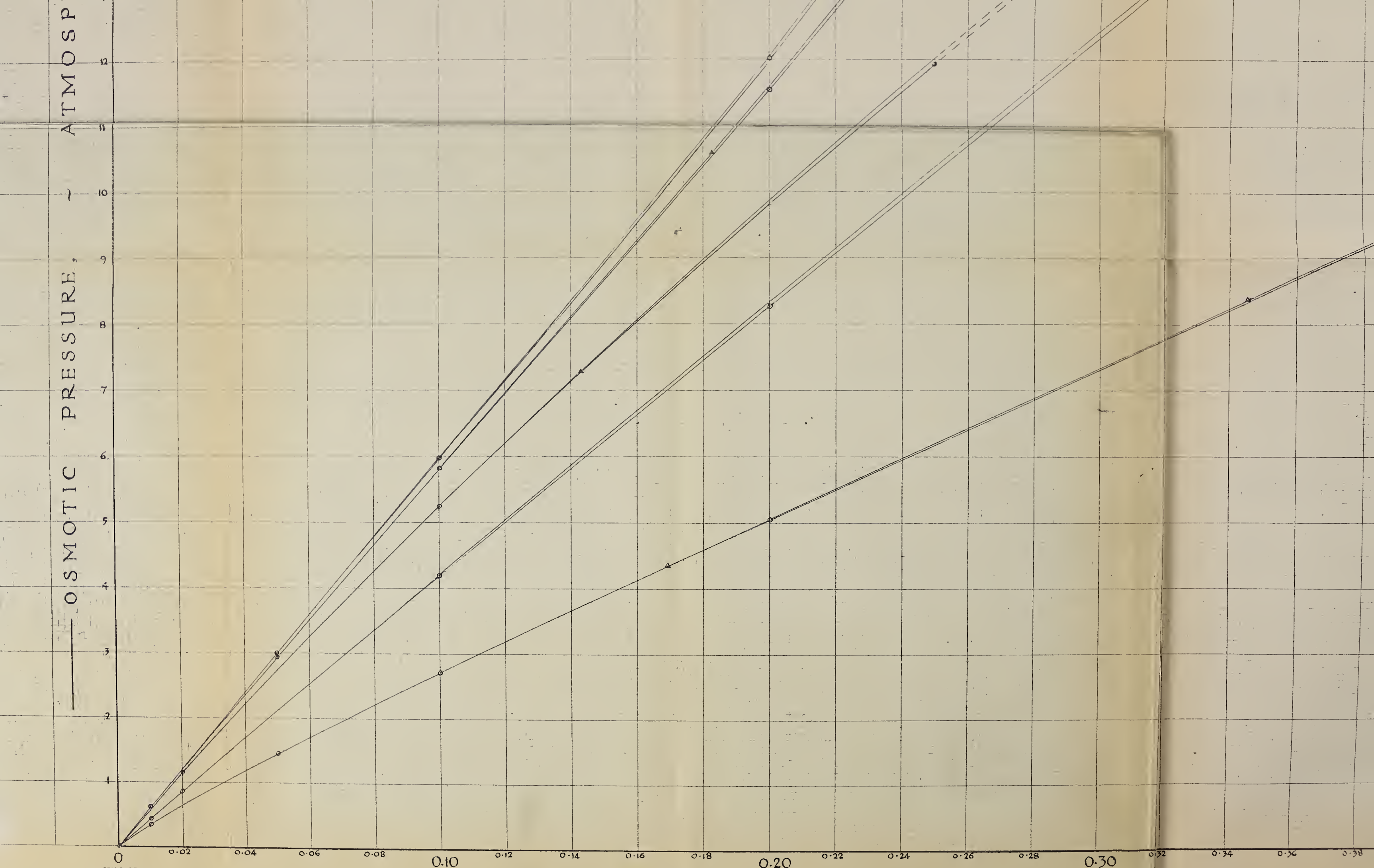
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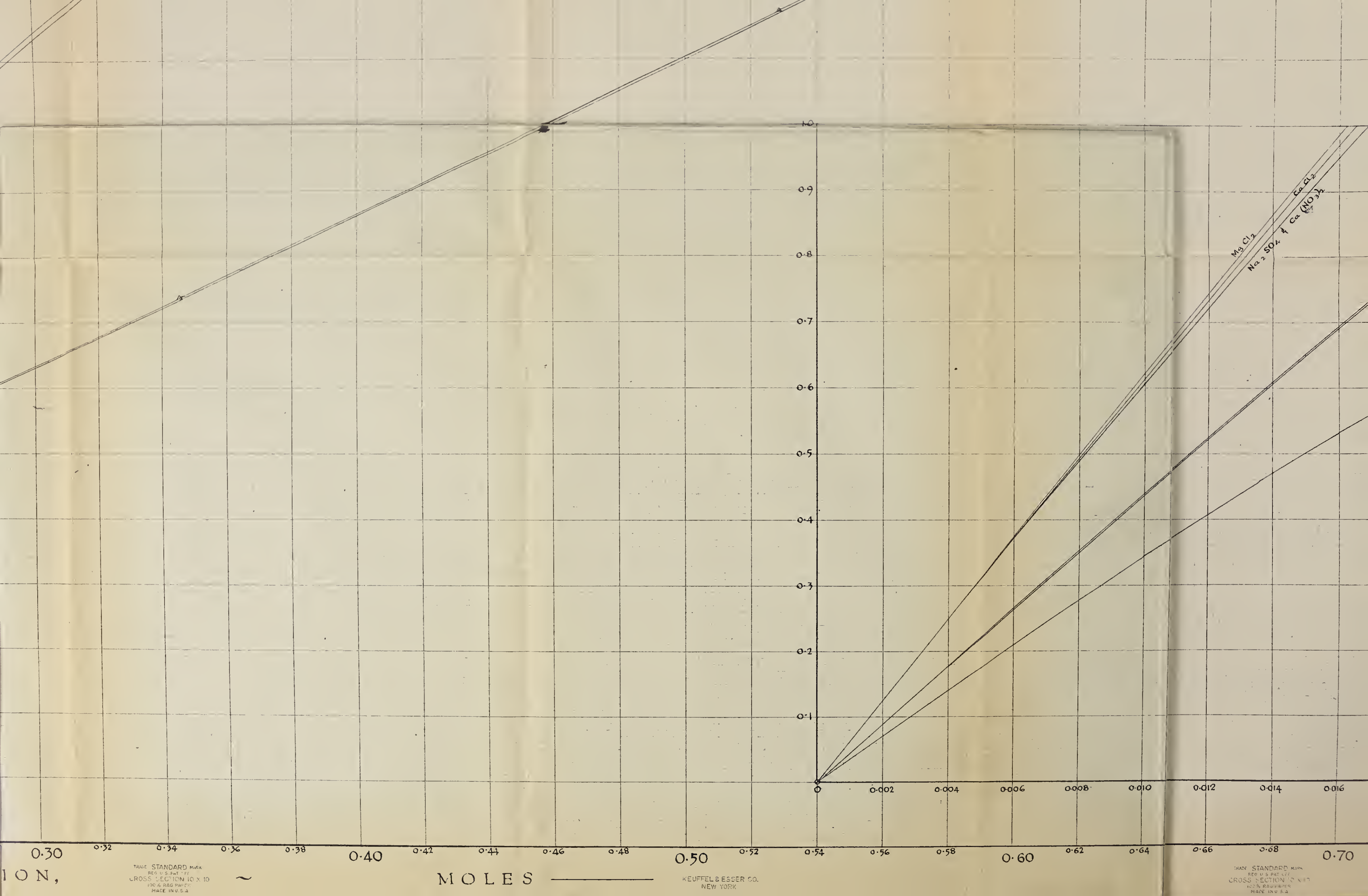
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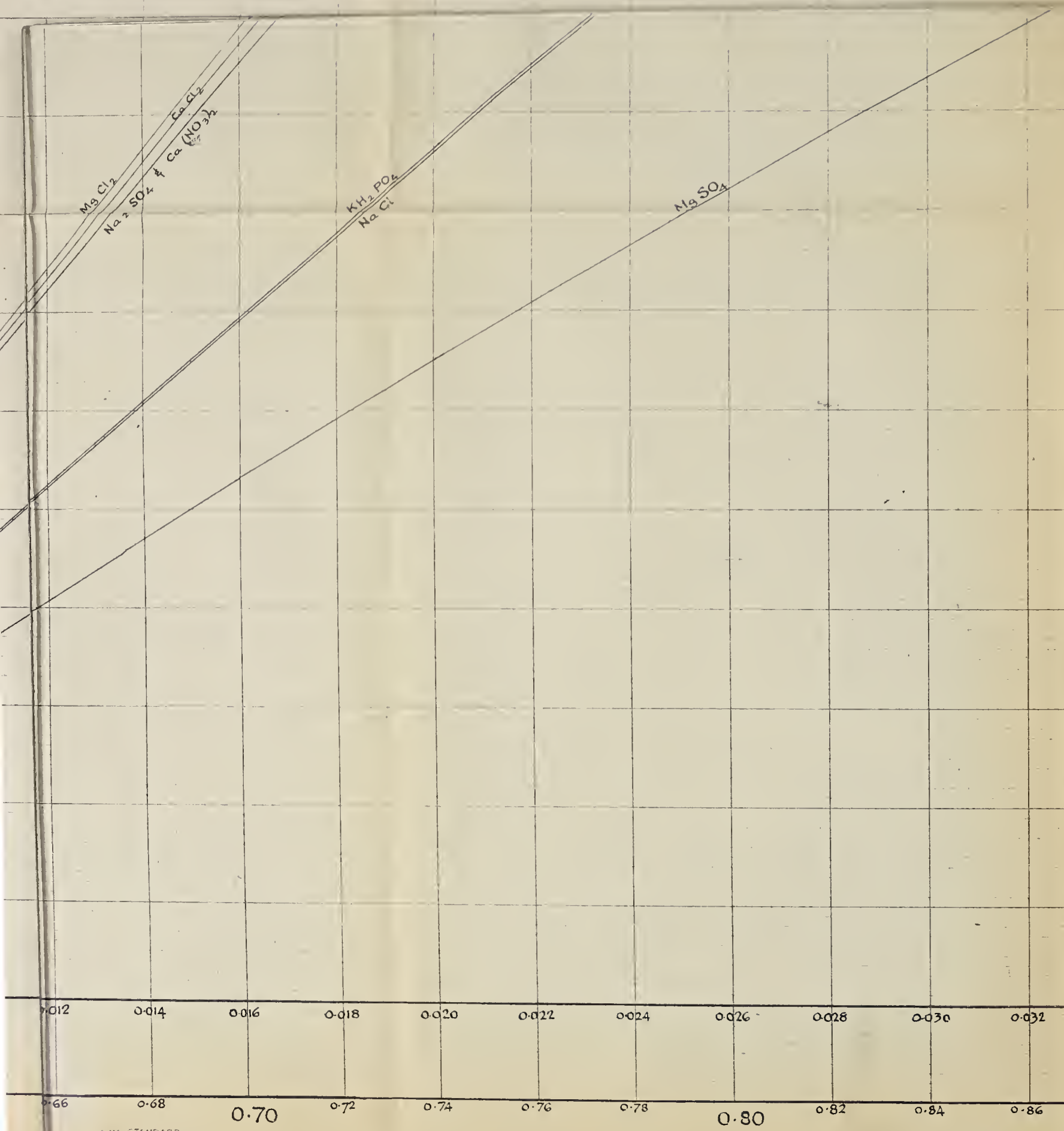
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THE OSMOTIC PRESSURES OF SALT SOLUTIONS ~ AS RELATED TO MOLAL AND MOLAR CONCENTRATIONS

DETERMINED FROM FREEZING POINT
DEPRESSIONS & DENSITY DATA APPEARING IN
INTERNATIONAL CRITICAL TABLES

LEGEND:—

- △— MOLAR CONCENTRATIONS
- MOLAL CONCENTRATIONS
- BEYOND SOLUBILITY AT FREEZING POINT

EXPANDED INSERT IS ESPECIALLY FOR CALCULATING
OSMOTIC PRESSURE OF BASE NUTRIENT SOLUTION

